US 20120197911A1

(19) United States

(12) Patent Application Publication

Banka et al.

(10) Pub. No.: US 2012/0197911 A1

(43) Pub. Date: Aug. 2, 2012

(54) SEARCHING SENSOR DATA

(75) Inventors: **Tarun Banka**, Milpitas, CA (US); **Manoj Kumar Pandey**, Milpitas, CA (US); **Debojyoti Dutta**, Santa Clara, CA (US); **Mainak Sen**, Fremont, CA (US); **Raja Suresh Krishna Balakrishnan**, San Jose, CA (US)

(73) Assignee: **CISCO TECHNOLOGY, INC.**, San Jose, CA (US)

(21) Appl. No.: **13/016,942**

(22) Filed: **Jan. 28, 2011**

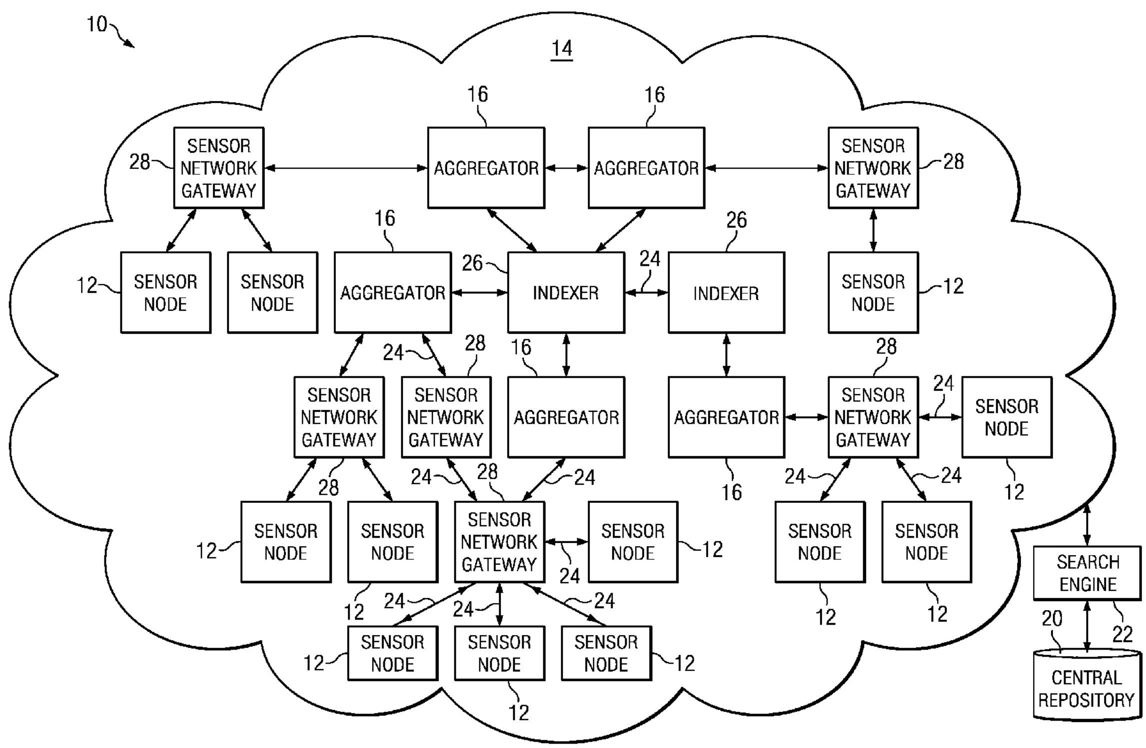
Publication Classification

(51) **Int. Cl.**
G06F 17/30 (2006.01)

(52) **U.S. Cl.** ... **707/752**; 707/759; 707/754; 707/E17.014

(57) **ABSTRACT**

In particular embodiments, a method includes receiving a query for particular sensor data among multiple sensor data from multiple sensors. The plurality of sensor data has been indexed according to a multi-dimensional array. One or more first ones of the dimensions include time, and one or more second ones of the dimensions include one or more predetermined sensor-data attributes. The method includes translating the query to correspond to the indexing of the plurality of sensor data. The translated query includes one or more values for one or more of the dimensions of the multi-dimensional array. The method includes communicating the translated query to search among the plurality of sensor data according to its indexing to identify the particular sensor data.



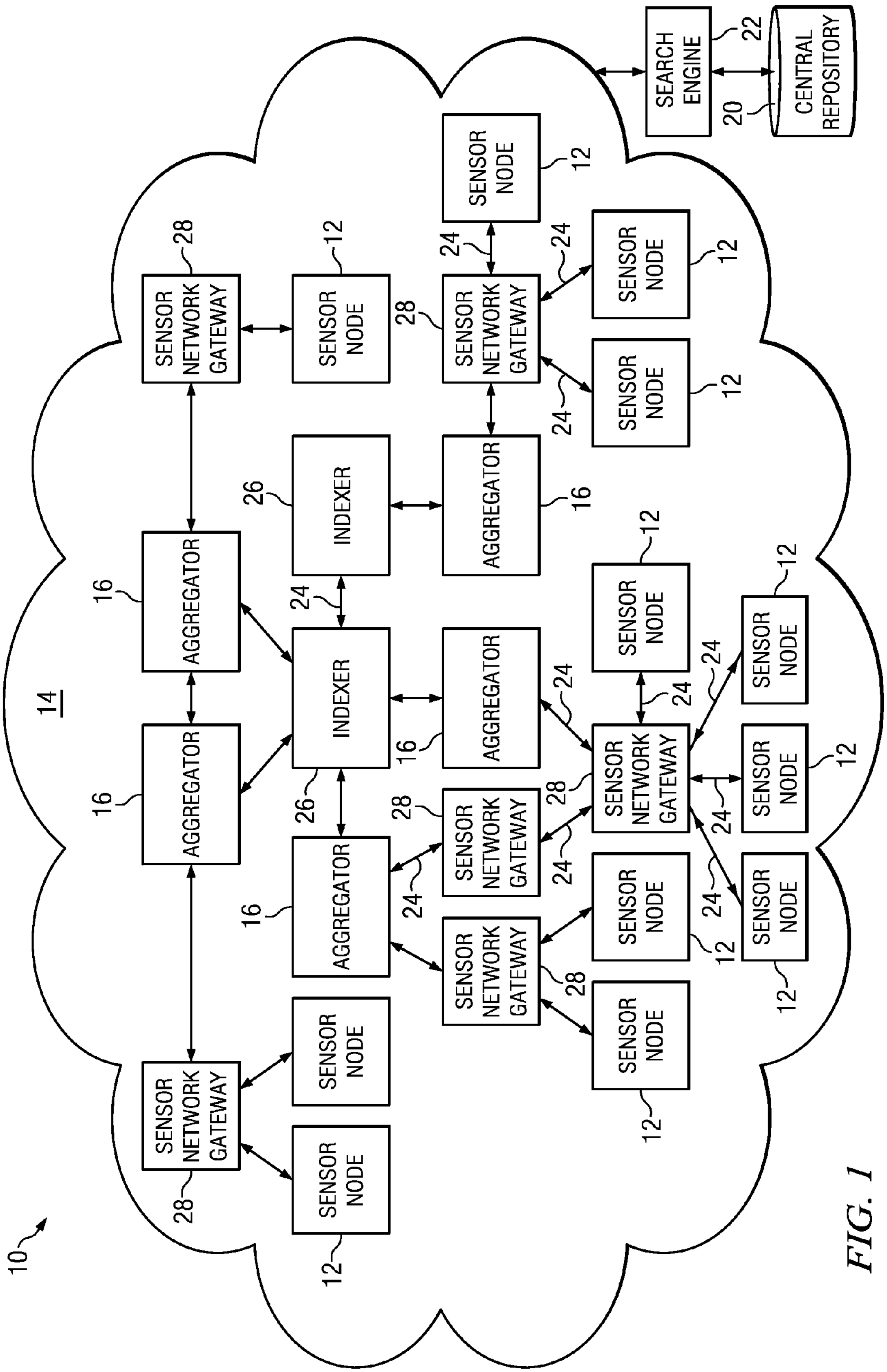

10
14
SEARCH ENGINE
22
20
CENTRAL REPOSITORY
SENSOR NODE
12
SENSOR NETWORK GATEWAY
28
24
AGGREGATOR
16
INDEXER
26

FIG. 1

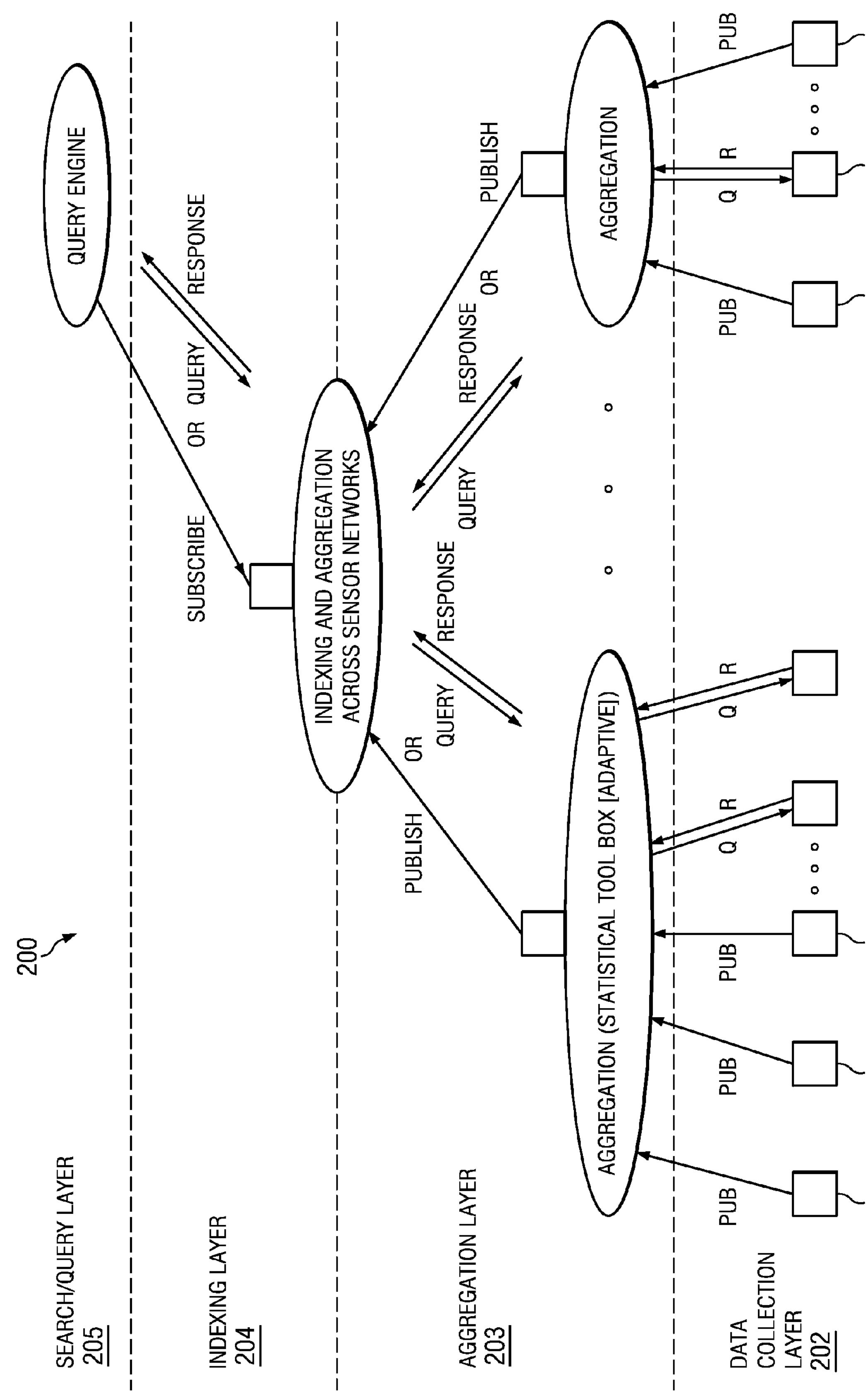

200
SEARCH/QUERY LAYER
205
INDEXING LAYER
204
AGGREGATION LAYER
203
DATA
COLLECTION
LAYER
202
QUERY ENGINE
SUBSCRIBE
OR QUERY
RESPONSE
INDEXING AND AGGREGATION
ACROSS SENSOR NETWORKS
PUBLISH
OR
QUERY
RESPONSE
QUERY
RESPONSE
OR
PUBLISH
AGGREGATION (STATISTICAL TOOL BOX [ADAPTIVE])
AGGREGATION
PUB
PUB
PUB
Q
R
Q
R
PUB
Q
R
PUB
201a
201b
201c
201d
201e
201f

FIG. 2

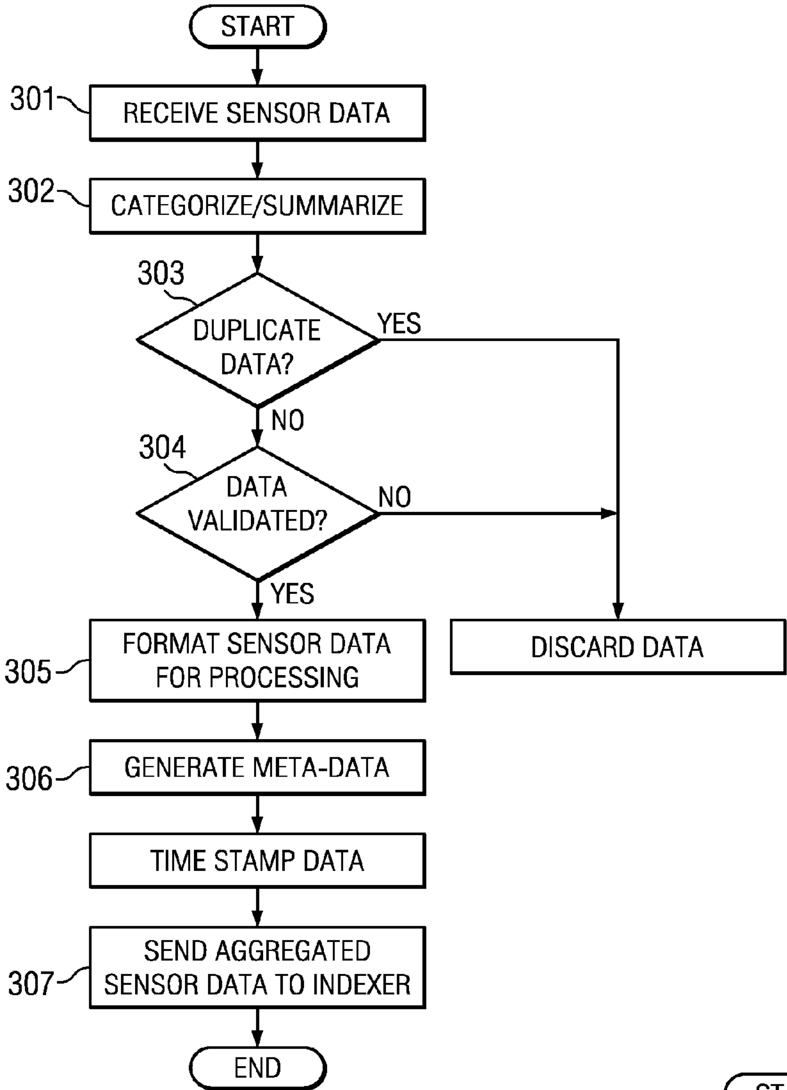

START
301
RECEIVE SENSOR DATA
302
CATEGORIZE/SUMMARIZE
303
DUPLICATE DATA?
YES
NO
304
DATA VALIDATED?
NO
YES
FORMAT SENSOR DATA FOR PROCESSING
305
DISCARD DATA
306
GENERATE META-DATA
TIME STAMP DATA
307
SEND AGGREGATED SENSOR DATA TO INDEXER
END

FIG. 3

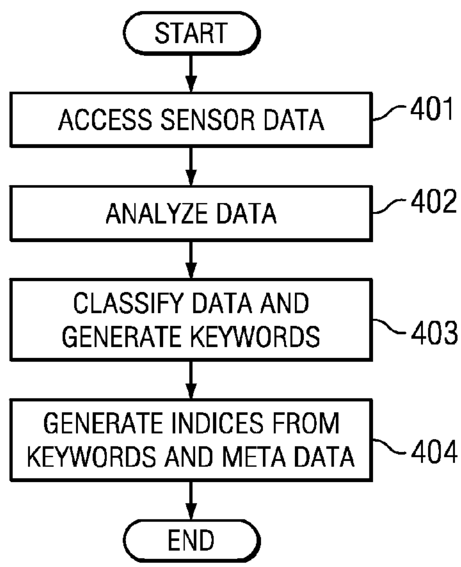

START
ACCESS SENSOR DATA
401
ANALYZE DATA
402
CLASSIFY DATA AND GENERATE KEYWORDS
403
GENERATE INDICES FROM KEYWORDS AND META DATA
404
END

FIG. 4

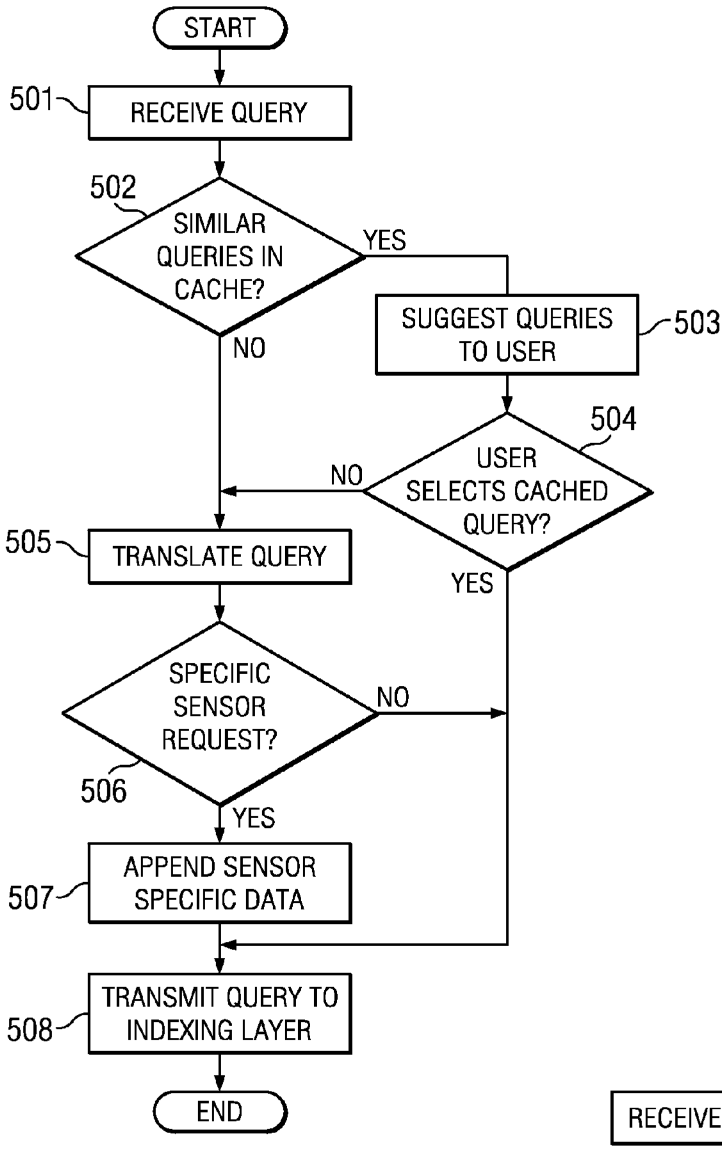

START
501
RECEIVE QUERY
502
SIMILAR QUERIES IN CACHE?
YES
SUGGEST QUERIES TO USER
503
NO
504
USER SELECTS CACHED QUERY?
NO
505
TRANSLATE QUERY
YES
SPECIFIC SENSOR REQUEST?
NO
506
YES
APPEND SENSOR SPECIFIC DATA
507
TRANSMIT QUERY TO INDEXING LAYER
508
END

FIG. 5

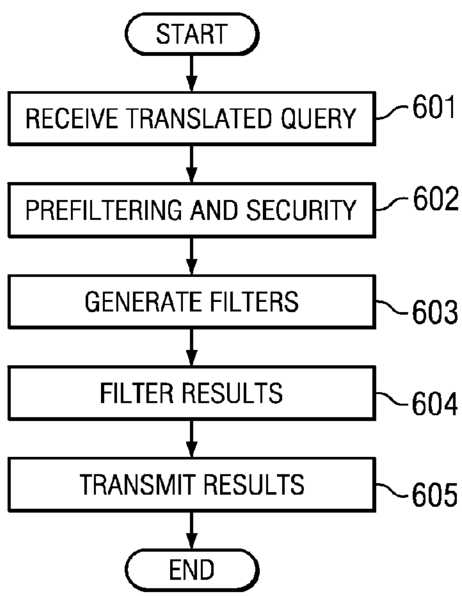

START
RECEIVE TRANSLATED QUERY
601
PREFILTERING AND SECURITY
602
GENERATE FILTERS
603
FILTER RESULTS
604
TRANSMIT RESULTS
605
END

FIG. 6

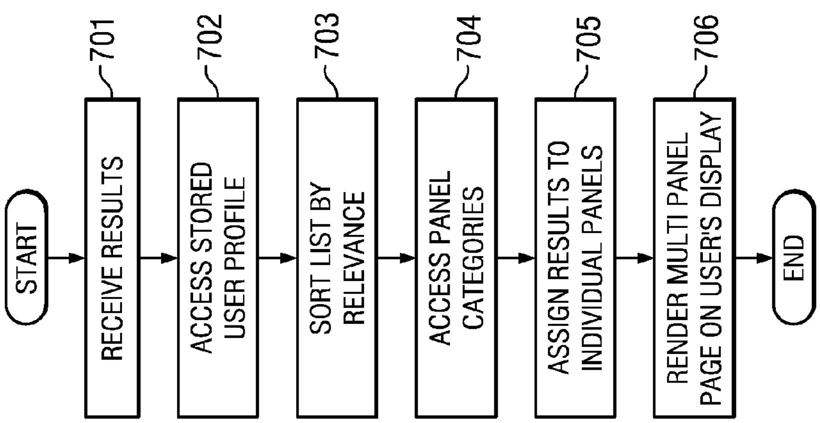

START
RECEIVE RESULTS
701
ACCESS STORED USER PROFILE
702
SORT LIST BY RELEVANCE
703
ACCESS PANEL CATEGORIES
704
ASSIGN RESULTS TO INDIVIDUAL PANELS
705
RENDER MULTI PANEL PAGE ON USER'S DISPLAY
706
END

FIG. 7

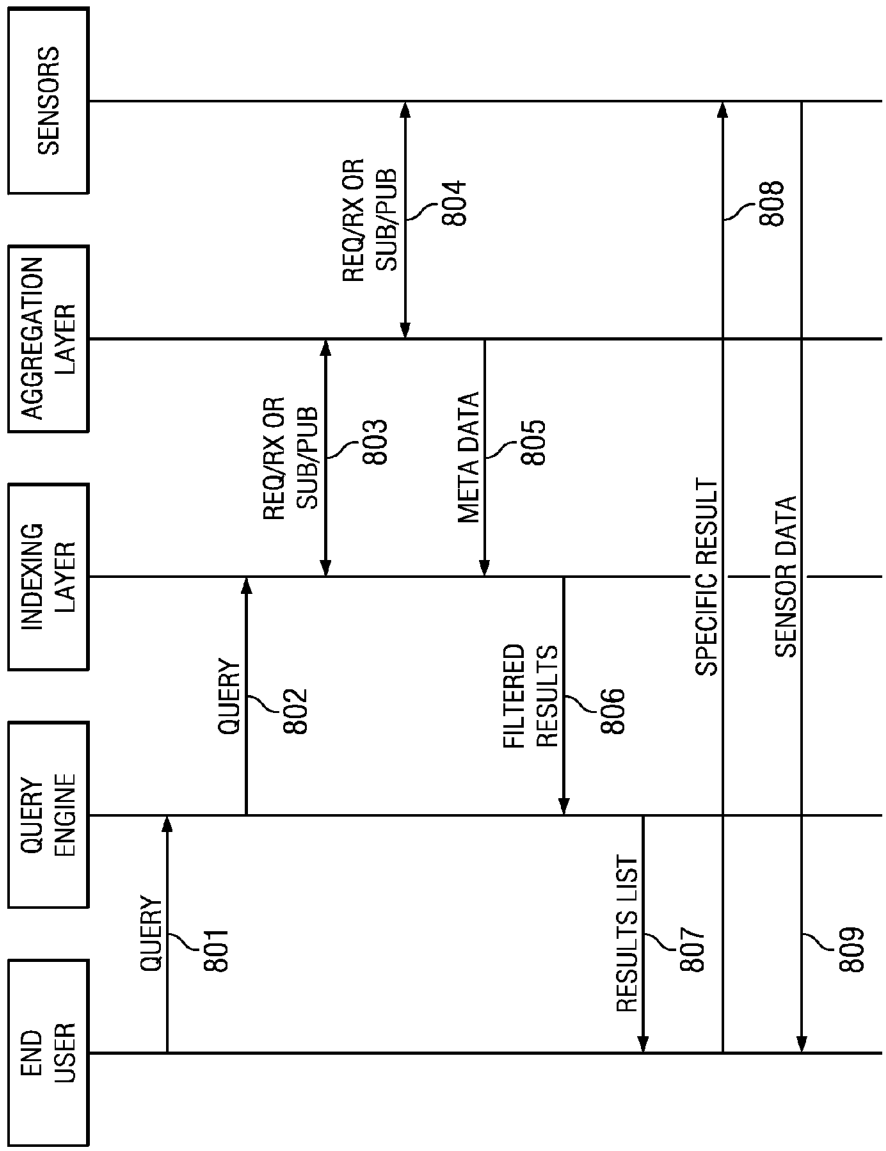

END USER
QUERY ENGINE
INDEXING LAYER
AGGREGATION LAYER
SENSORS
QUERY
801
QUERY
802
REQ/RX OR SUB/PUB
803
REQ/RX OR SUB/PUB
804
META DATA
805
FILTERED RESULTS
806
RESULTS LIST
807
SPECIFIC RESULT
808
SENSOR DATA
809

FIG. 8

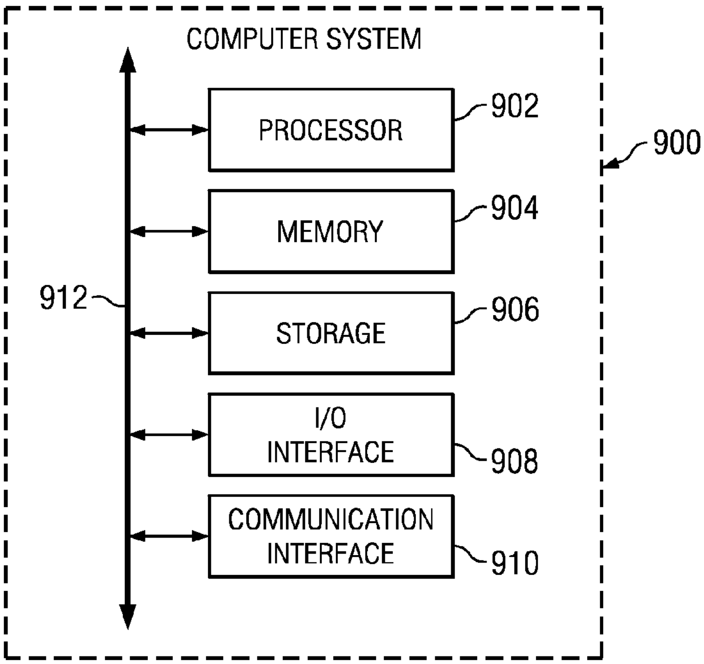

COMPUTER SYSTEM
PROCESSOR
902
900
MEMORY
904
912
STORAGE
906
I/O INTERFACE
908
COMMUNICATION INTERFACE
910

FIG. 9

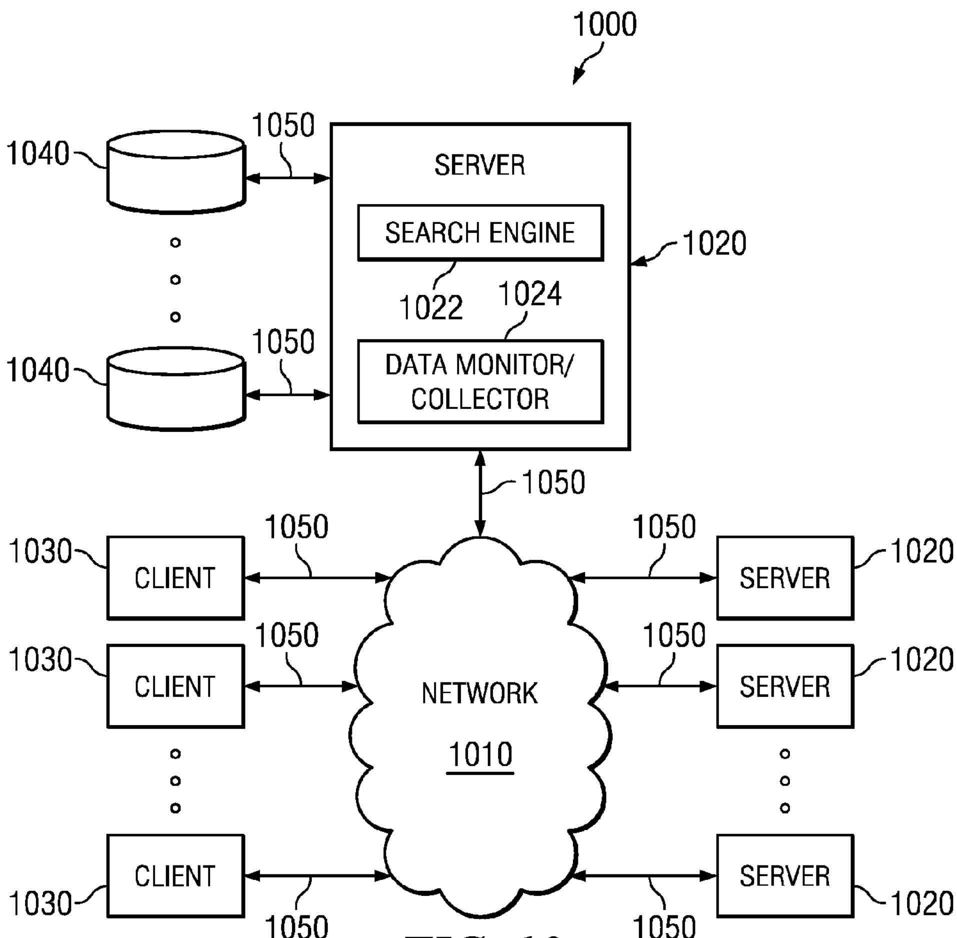

1000
1040
1050
SERVER
SEARCH ENGINE
1020
1022
1024
1040
1050
DATA MONITOR/ COLLECTOR
1050
1030
1050
CLIENT
1050
SERVER
1020
1030
1050
CLIENT
1050
SERVER
1020
NETWORK
1010
1030
CLIENT
1050
1050
SERVER
1020

FIG. 10

SEARCHING SENSOR DATA

TECHNICAL FIELD

[0001] This disclosure generally relates to sensor networks.

BACKGROUND

[0002] A sensor network may include distributed autonomous sensors. Uses of sensor networks include but are not limited to military applications, industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, utility usage, healthcare applications, home automation, and traffic control. A sensor in a sensor network is typically equipped with a communications interface, a controller, and an energy source (such as a battery).

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] FIG. **1** illustrates an example sensor network.
[0004] FIG. **2** illustrates an example hierarchy of example network layers for collecting, aggregating, indexing, and querying sensor data.
[0005] FIG. **3** illustrates an example method for aggregating sensor data.
[0006] FIG. **4** illustrates an example method for indexing sensor data.
[0007] FIG. **5** illustrates an example method for generating a sensor-data query.
[0008] FIG. **6** illustrates an example method for retrieving sensor data in response to a sensor-data query.
[0009] FIG. **7** illustrates an example method for presenting sensor data retrieved in response to a sensor-data query.
[0010] FIG. **8** illustrates an example communication flow for collecting, aggregating, indexing, and querying sensor data.
[0011] FIG. **9** illustrates an example computer system.
[0012] FIG. **10** illustrates an example network environment.

DESCRIPTION OF EXAMPLE EMBODIMENTS

Overview

[0013] In particular embodiments, a method includes receiving a query for particular sensor data among multiple sensor data from multiple sensors. The plurality of sensor data has been indexed according to a multi-dimensional array. One or more first ones of the dimensions include time, and one or more second ones of the dimensions include one or more pre-determined sensor-data attributes. The method includes translating the query to correspond to the indexing of the plurality of sensor data. The translated query includes one or more values for one or more of the dimensions of the multi-dimensional array. The method includes communicating the translated query to search among the plurality of sensor data according to its indexing to identify the particular sensor data.

Description

[0014] FIG. **1** illustrates an example sensor network. Particular embodiments may facilitate operation of an "Internet of things," with a diverse group of sensors in a hierarchical, multi-sink sensor network. Sensor network **10** includes multiple sensor nodes **12** that collect sensor data, possibly from diverse geographic locations. The sensor nodes are connected via a communication network **14** including network links **24**, and sensor-network gateways **28**. In particular embodiments, each sensor node **12** communicates only with one sensor-network gateway **28**. Each sensor-network gateway **28** may link together multiple sensor nodes **12**. Sensor nodes **12** may be grouped together based on geographic or logical location, type of data, or other criteria. Each sensor-network gateway **28** may be connected via communication link **24** to one or more aggregator nodes **16**. Aggregators **16**, also called aggregation nodes **16**, perform in-network processing of the raw sensor data and format the data into a format that may be more readily indexed by indexers **26**. Indexers **26**, (also called indexer nodes) provide to a search engine **22** information about what data is available at each aggregator node **16** (and therefore each sensor node **12** attached to aggregator node **16**). End-users (not shown) may issue queries through search engine **22**. Search engine **22** may generate a query from the user's inputs that takes advantage of the indexing format applied by indexer nodes **26**. The query is routed to one or more indexer nodes **26**, and each indexer **26** searches its own internal data store to find aggregator nodes **16** with matching data. In response, each indexer **26** returns the metadata of the sensor data matching the query or, alternatively, routes the query to another indexer **26** that may have data matching the query. In particular embodiments, central repository **20** stores various cached data related to query generation and response, such as popular queries, the results for popular queries, or end-user profiles. Central repository **20** and search engine **22** may alternatively be implemented by indexer nodes **26**, or included in the communication network **14**. Although this disclosure describes and illustrates a particular number of and arrangement among sensor network **10**, sensor nodes **12**, communication network **14**, aggregator nodes **16**, central repository **20**, search engine **22**, indexer nodes **26**, and sensor-network gateways **28**, this disclosure contemplates any suitable number of and arrangement among sensor network **10**, sensor nodes **12**, communication network **14**, aggregator nodes **16**, central repository **20**, search engine **22**, indexer nodes **26**, and sensor-network gateways **28**.

[0015] This disclosure contemplates any suitable communication network **14**. As an example and not by way of limitation, one or more portions of communication network **14** may include an ad hoc network, an intranet, an extranet, a virtual private network (VPN), a local area network (LAN), a wireless LAN (WLAN), a wide area network (WAN), a wireless WAN (WWAN), a metropolitan area network (MAN), a portion of the Internet, a portion of the Public Switched Telephone Network (PSTN), a cellular telephone network, or a combination of two or more of these. Communication network **14** may include one or more communication networks.

[0016] Sensor network **10** may include multiple sensor networks. Each sensor network communicates to the outside world through its sensor-network gateway **28**. In particular embodiments, all data from individual sensor nodes **12** must pass through a sensor-network gateway **28** to reach an aggregator node **16**. Each sensor-network gateway **28** may include a physical address, which may be longitude latitude coordinates of sensor-network gateway **28**, or a radius of the physical area its sensor nodes **12** cover, and a logical address used for routing and addressing of data.

[0017] In particular embodiments each sensor-network gateway **28** implements a security policy using an access list that limits access to the data available from sensor network **10**. Well-known symmetric key cryptography schemes may be used to initiate a secure session between end-users and sensor-network gateways **28** for data exchange. In this architecture, indexer nodes **26** may also be used as authentication servers (AS) to exchange secret keys for the session between end-users and the sensor network where data is available. This requires that end-users' private key and sensor networks' private key is known to the indexer (acting as an authentication server) where end-users search request finds a match for the desired data. A session key is sent back to the end-user that is exchanged with sensor network. This session key is used to exchange data between end-users and the sensor networks for the validity of the session key in a secured manner.

[0018] Sensor network **10** includes one or more sensor nodes **12**. In particular embodiments, a sensor node **12** includes one or more devices that may measure or otherwise sense one or more physical quantities and convert the sensed physical quantities into or generate based on the sensed physical quantities one or more signals. Example physical quantities include but are not limited to chemical concentration, electrical fields, gravity, humidity, light, location, magnetic fields, motion, orientation, pressure, shear stress, sound, temperature, tension (or compression), torsion, and vibration. A signal may be a digital or analog electrical signal. Example sensor nodes **12** include but are not limited to an audio sensor, electricity meter, gas meter, Global Positioning System (GPS) locator, motion detector, potentiometer (which may, for example, operate as a fuel gauge), pressure sensor (which may, for example, operate as an altimeter, barometer, depth sensor, flow sensor, or leak sensor), still or video camera, thermometer, and water meter. In particular embodiments, sensor node **12** may include one or more sensor nodes **12** and may be unitary or distributed. Sensors may be static or mobile, connecting to various different sensor networks depending on where it is located, such as mobile phone. This disclosure contemplates any suitable sensor nodes **12**.

[0019] In particular embodiments, one or more sensor nodes **12** each include one or more devices that may send, receive, or forward information (such as sensor data) over a communication channel, for example to one or more other sensor nodes **12** or other equipment in sensor network **10** or to aggregator nodes **16**. In particular embodiments, sensor data are one or more signals that one or more sensor nodes **12** have converted one or more sensed physical quantities into or generated based on one or more sensed physical quantities. In particular embodiments, a sensor-data stream is a sequence of sensor data generated by a sensor node **12**, which sensor node **12** may transmit more or less continuously as it generates the sensor data or periodically in batches. Reference to sensor data may encompass a sensor-data stream, and vice versa, where appropriate. Sensor data may relate to a sensor subject. This disclosure contemplates any suitable sensor subject. As an example and not by way of limitation, a sensor subject may be a person (or group of persons), place (such as for example a geographical location), thing (such as for example a building, road, or car model), concept, discipline, time period, event, field of study, interest, issue, knowledge base, topic, or other sensor subject. Sensor data or a sensor-data stream may relate to a sensor subject in any suitable way. As an example and not by way of limitation, sensor data may relate to a sensor subject because one or more sensor nodes **12** generated the sensor data from one or more stimuli produced by the sensor subject. As another example, sensor data may relate to a sensor subject because the sensor data may provide insight or further understanding of the sensor subject. As another example, sensor data may relate to a sensor subject because it may help detect or predict the occurrence of one or more problems or events concerning the sensor subject. As another example, sensor data may relate to a sensor subject because it may facilitate monitoring of the sensor subject.

[0020] In particular embodiments, when a sensor node **12** transmits sensor data, sensor node **12** may tag the sensor data or otherwise identify it as being related to a particular sensor subject. As an example and not by way of limitation, a sensor node **12** may have one or more sensor identifiers (IDs) and generate only particular sensor data related to a particular sensor subject. One or more sensor nodes **12** may be connected to a network (such as for example an Internet Protocol (IP) network) that assigns unique identifiers to each terminal node. A network host may assign an IP address to each sensor node **12**, and the IP address assigned to sensor node **12** may provide a sensor ID for sensor node **12**. As another example, one or more sensor nodes **12** may each have a network interface with a unique ID (such as for example a Media Access Control (MAC) address, an Ethernet hardware address (EHA) or another hardware address, an adapter address, or a physical address) and the unique ID of the network interface may provide a sensor ID for sensor node **12**. As another example, geographic information about a sensor node **12** (such as for example the geographic location of sensor **201** as identified by the Global Positioning System (GPS)) may provide a sensor ID for sensor **201**. As another example, one or more properties of a sensor node **12** (such as for example its sensor type) may provide a sensor ID for sensor node **12**. When a sensor transmits sensor data that it has generated, sensor node **12** may transmit the sensor data along with one or more sensor IDs of sensor node **12**. The present disclosure contemplates any suitable sensor IDs containing any suitable information. As an example and not by way of limitation, a sensor ID for a sensor node **12** may be a combination of two or more of the sensor IDs described above, where appropriate. Moreover, the present disclosure contemplates any suitable tags for sensor data. In other embodiments, to save power and processing resources, tagging is performed by aggregator nodes **16**, and sensor nodes **12** do not perform tagging.

[0021] In particular embodiments, a sensor node **12** may have one or more resources for carrying out its functions. These resources may include but are not limited to processing capabilities, memory, and power. Sensor **12** may have one or more processors and one or memory devices. This disclosure contemplates sensor node **12** having any suitable number of any suitable processors and memory devices. Sensor **12** may have an internal power source (such as for example one or more rechargeable or replaceable batteries) or receive power from an external power source (such as for example an electrical grid). Sensor **12** may include one or more solar panels to provide power to it. This disclosure contemplates sensor nodes **12** having any suitable sources of power. Other resources of sensor node **12** may but need not in all cases include software, such as for example application software, middleware, system software, firmware, and device drivers. This disclosure contemplates sensor node **12** including any suitable resources for carrying out its functions. All sensor nodes **12** in sensor network **10** need not have the same resources; different sensor nodes **12** may have different resources. As an example and not by way of limitation, one or more first sensor nodes **12** may each have substantial processing capabilities, large amounts of memory, and almost unlimited power, while one or more second sensor nodes **12** may each have very limited processing capabilities, memory, and power. As another example, one or more first sensor nodes **12** may each have software running on them enabling them to perform a variety of functions (including higher-level ones such as tagging sensor data), while one or more second sensor nodes **12** may each have less or scaled-down software running on them enabling them to perform fewer functions (or only lower-level ones). This disclosure contemplates any suitable diversity in the resources available to sensor nodes **12** throughout system **10**.

[0022] Although FIG. **1** illustrates a particular arrangement of sensor nodes **12**, sensor-network gateways **28**, aggregator nodes **16**, indexer nodes **26**, and search engine **22**, this disclosure contemplates any suitable arrangement of sensor nodes **12**, sensor-network gateways **28**, aggregator nodes **16**, indexer nodes **26**, and search engine **22**. Moreover, although FIG. **1** illustrates a particular number of sensor nodes **12**, sensor-network gateways **28**, aggregator nodes **16**, indexer nodes **26**, and search engine **22**, this disclosure contemplates any suitable number of sensor nodes **12**, sensor-network gateways **28**, aggregator nodes **16**, indexer nodes **26**, and search engine **22**. Any suitable connections may connect sensor nodes **12**, sensor-network gateways **28**, aggregator nodes **16**, indexer nodes **26**, and search engine **22**.

[0023] In particular embodiments, an aggregator node **16** is a node in a system that collects sensor-data from a set of sensor nodes **12** (which may be a subset of all sensor nodes **12** in a sensor network **10**). The set of sensor nodes **12** that an aggregator node **16** may collect sensor data from may, as an example and not by way of limitation, include sensor nodes **12** that are within a physical or logical neighborhood of aggregator node **16**. An aggregator node **16** may include one or more computer systems (such as, for example, servers) and may be unitary or distributed. An aggregator node **16** may include one or more aggregator nodes **16**. Aggregator node **16** may provide an infrastructure for collecting and aggregating data from sensor nodes **12**. In particular embodiments, each aggregator node **16** is responsible for collecting sensor data from a set of sensor nodes **12** in its physical or logical neighborhood. Aggregator node **16** may collect and aggregate a particular set of data from the set of sensor nodes **12** or all sensor data generated by the set of sensor nodes **12**. Each sensor node **12** may transmit a sensor-data stream to one or more aggregator nodes **16**. As an example and not by way of limitation, each sensor node **12** may transmit a sensor-data stream to nearest aggregator node **16**. A sensor node **12** may periodically inform one or more aggregator nodes **16** about the sensor data that it has generated or may update its aggregator node **16** only when deemed necessary. In particular embodiments, aggregator nodes **16** may operate hierarchically, such that an aggregator node **16** may collect data from one or more other aggregator nodes **16**.

[0024] In particular embodiments, sensor network **10** uses a query-response infrastructure with programmable primitives. As an example and not by way of limitation, indexer nodes **26** may receive one or more queries (such as, for example, from a search engine **22**) for real-time sensor data from particular subjects. Indexer nodes **26** may send one or more requests for the sensor data to aggregator nodes **16** and sensor nodes **12**. This request may include information describing the query and instruction for how to aggregate the sensor data from sensor nodes **12**. Sensor nodes **12** may then respond by transmitting the requested sensor data to aggregator nodes **16**, which may aggregate the data and respond by transmitting the aggregated data to indexer nodes **26**.

[0025] In particular embodiments, aggregator nodes **16** may be programmable to support any request or query for data from a search engine **22**. In other embodiments, aggregator nodes **16** may have some pre-defined functions or macros over which aggregator nodes **16** may aggregate. As an example and not by way of limitation, macros may include wavelet, Fast Fourier Transform (FFT) decomposition, or other fingerprinting techniques. In particular embodiments, macros may be hardware accelerated in DSPs and FPGAs, such as FFT, enabling wire speed summarization.

[0026] In particular embodiments, an aggregator node **16** may aggregate sensor data using spatial factors. An aggregator node **16** may collect data from one or more sensor nodes **12** that are spatially nearby neighbors. Aggregator node **16** may then provide a statistical characterization of the sensor data generated by a set of sensor nodes **12**. As an example and not by way of limitation, an aggregator node **16** may provide a mean, median, mode, standard deviation, Gaussian distribution, log-normal, other suitable characterization of the data, or two or more such characterizations of the data. Aggregator node **16** may collect and provide the statistical characterization of the data in real-time, and transmit this data to indexer nodes **26** in real-time.

[0027] In particular embodiments, an aggregator node **16** may aggregate sensor data using temporal factors. An aggregator node **16** may collect data from one or more sensor nodes **12** based on a time-series of the sensor data. Aggregator node **16** may then provide a statistical characterization of the sensor data generated by a set of sensor nodes **12**. As an example and not by way of limitation, an aggregator node **16** may provide a moving average, or autoregressive or integrated or a combination of the aforementioned models. The time period over which aggregator node **16** may collect data may be any suitable finite time period. As an example and not by way of limitation, the time period may be a predefined window as defined by a query, request, macro, or function.

[0028] In particular embodiments, an aggregator nodes **16** may aggregate sensor data using both spatial and temporal factors. An aggregator node **16** may collect data from one or more sensor nodes **12** based both the spacial proximity of sensor nodes **12** and on the time-series of the sensor data. In particular embodiments, complex sensor data with multidimensional and temporal characteristics may be aggregated using multilinear algebraic techniques (such as, for example, tensor decomposition) and aggregator node **16** may only transmit key coefficients to indexer nodes **26**.

[0029] In particular embodiments, indexer nodes **26** and aggregator nodes **16** use a publish-subscribe infrastructure with programmable primitives. As an example and not by way of limitation, a indexer node **26** may receive one or more queries (such as, for example, from a search engine **22**) for real-time sensor data in a particular geographic area. Indexer nodes **26 28** may send one or more requests for the sensor data to aggregator nodes **16** and sensor nodes **12**. This request may include information describing the query and instruction for how to aggregate the sensor data from sensor nodes **12**. Sensor nodes **12** may then publish sensor data to aggregator nodes **16**, which may aggregate the data and publish the data to indexer nodes **26**. In particular embodiments, a user of search engine **22** may subscribe to indexer nodes **26** and may receive push notification of aggregated data at aggregator node **16** and statistical characterizations of sensor data from aggregator node **16**.

[0030] FIG. **2** illustrates an example hierarchy of example network layers for collecting, aggregating, indexing, and querying sensor data **200**. At the lowest layer sits the data collection layer **201**. The data collection layer **201** comprises a plurality of sensor networks **202***a-f*, each sensor network comprising a plurality of individual sensor nodes **12** and a sensor-network gateway **28**.

[0031] Data collection layer **201** passes sensor data to aggregation layer **203**. Aggregation layer **203** aggregates data from multiple sensor networks and performs in-network processing on the raw data. Aggregation layer **203** comprises a plurality of aggregator nodes **16**, each aggregator node **16** connected to multiple sensor-network gateways **28**. Aggregators **16** perform the bulk of processing of data, including eliminating redundant data through a serious of deduplication algorithms, data summarization and categorization, and data validation. Aggregation layer **203** also generates metadata and formats the sensor data into a format which may be easily indexed for searching. Aggregation layer **203** may have multiple hierarchical levels; one aggregator **26** may be logically located below another aggregator node **16**, and feed its aggregated data up to other aggregator nodes **16**.

[0032] In particular embodiments, aggregation layer **203** may include one or more computer systems (such as for example servers) and may be unitary or distributed. Aggregation layer **203** may include one or more aggregator nodes **16**. This disclosure contemplates any suitable aggregation layer **203**. As an example and not by way of limitation, a sensor network may store sensor data and transmit it to aggregation layer **203** periodically in batches. As another example, sensor networks may continuously transmit sensor data to aggregation layer **203** as they generate the sensor data. As another example, sensor network may transmit sensor data to aggregation layer **203** after receiving a request for sensor data from, for example, aggregation layer **203**, indexing layer **204**, or the search-query layer **205**. As another example, sensor networks may transmit sensor data to aggregation layer **203** after receiving an indication that one or more persons or entities (which may be a sensor subject of the sensor data) have consented to or authorized the transmission of the sensor data.

[0033] In particular embodiments, aggregation layer **203** may store, categorize, combine, and file data from one or more data streams from one or more sensor networks over time. In particular embodiments, aggregation layer **203** may combine and store data sets based on a variety of criteria. For example, aggregation layer **203** may combine data sets from a plurality of data streams based on a particular sensor subject, such as for example a specific person or group of persons the sensor is monitoring, a location or environment the sensor is monitoring, a type of sensor, a time period or event when the sensor recorded the data, other appropriate criteria, or a combination of two or more such criteria. As another example, aggregation layer **203** may combine data sets from a plurality of data streams based on time, such as for example by using a moving average or auto-regressive algorithm. As another example, aggregation layer **203** may combine data sets from a plurality of data streams based on the geography of sensor networks that generated the data streams, such as for example aggregating data based on the spatial correlation of sensor networks. As another example, aggregation layer **203** may combine data sets from a plurality of data streams based on pre-defined characteristics of the data streams, such as for example aggregating data based on a query, offer, or user-input that specifies a particular suitable characteristic that may serve as a basis for aggregation.

[0034] In particular embodiments, sensor networks may be probed periodically for sensor data. As an example and not by way of limitation, a query may be routed from a requesting system (such as search query layer **205**, indexing layer **204**, or aggregation layer **203**) to one or more sensor nodes **12** in a sensor network. The sensor may respond by transmitting a data stream containing some or all of the data requested. Aggregation layer **203** may then store, categorize, combine, and file some or all of this data. Aggregation layer **203** may also transmit some or all of this data to one or more other systems, such as for example indexing layer **204** or search query layer **205**. In particular embodiments, aggregation layer **203** may support publish-subscribe (pub-sub) communication paradigm. In such a publish-subscribe model, sensor nodes **12** blog data with authentication constraints to a pub-sub server. This server might do aggregate queries and might further send another publish message to another pub-sub server. In some embodiments, aggregator nodes **16** act as the pub-sub servers. Each pub-sub server acts as a heavy weight sensor node which does in-network processing based on policy engines. Since this system is hierarchical, and the pub-sub servers may form a topology that is resilient, it may scale to millions of sensor nodes **12**. These pub-sub servers act as micro-sinks and could function as in-network content routers. A pub-sub protocol is open and universal like XMPP (Jabber) or Twitter.

[0035] Indexing layer **204** performs indexing of data aggregated by aggregation layer **203**. Indexing layer **204** is comprised of any number of individual indexing nodes. Because each sensor data may comprise a real-time stream of data, searching data, even the summarized data from aggregation layer **203**, is of little use to an end-user unless the data is indexed. Indexing layer **204** generates keywords and indices for the aggregated real-time data streams such that a stream of data is easily searched and identified by various criteria. Indexing layer **204** is also hierarchical; indexer nodes **26** may be connected to other indexer nodes **26** at different levels. Thus, query to a particular indexer may be routed from other indexer nodes **26** in indexing layer **204**.

[0036] Indexing layer **204** receives queries from search-query layer **205**. Queries may be generated by end-users at a search interface, such as a website, or generated automatically by applications residing on computing devices. For example, a user may request traffic and weather conditions along a route programmed into a GPS navigation device. The navigation device has an API allowing the navigation route to be entered as a query, and includes preformatted criteria requesting sensor data requesting traffic and weather conditions. Search-query layer **205** may be a separate network, or may be part of indexing layer **204**. In response to the queries, indexer nodes **26** deliver a list of relevant aggregator nodes **16** (and therefore, sensor networks) serving the data matching the specifications of the query.

[0037] Every layer of system **200** may communicate data to the layer above it either through a subscribe/publish mechanism, or a request/receive model. For example, sensor nodes **12** in sensor networks may receive requests from a specific aggregator, and only transmit its collected sensor data in response to a request. Alternatively, a sensor network may receive a subscribe message from an aggregator, subscribing to all or a part of the sensor data collected by the sensor network. The subscribe message may specify continuous, periodic, or conditional data delivery. After the sensor network receives the subscribe message, it actively publishes collected sensor data to the subscribing aggregator pursuant to the timing specified in the subscribe message.

[0038] Particular embodiments may provide a standardized frame work for the exchanges of sensor data. Sensor networks may communicate using any suitable data format, such as for example JAVASCRIPT Object Notation (JSON), YAML Ain't Markup Language (or Yet Another Markup Language) (YAML), Hierarchical Data Format (HDF), Ordered Graph Data Language (OGDL), Extensible Markup Language (XML), Extensible Messaging and Presence Protocol (XMPP), or other suitable formats. As an example and not by way of limitation, sensor nodes **12** in sensor network **200** may communicate sensor data using XML. Standardization may facilitate the interoperability among sensor networks, aggregation layer **203**, indexing layer **204**, and search and search-query layer **205**. In particular embodiments, sensor data may be include definitions, categories, or other annotations in the header format of transport or routing protocols, and sensor nodes **12** may transmit one or more data streams using these options. These options may be identified by a type, relations, or subject, and may represent various sensor-related information.

[0039] FIG. **3** illustrates an example method for aggregating sensor data. Providing search to navigate and look-up sensor data is an important service; otherwise, it would simply be un-scalable for end-users to retrieve relevant information from vast amount of sensor data. However, the vast amount of data presents a unique challenge for building a scalable sensor search system. An architecture to support such a system needs support from several design elements that may assist and interact with each other. The aggregator is the gateway through which raw sensor data travels outwards towards the end-user. The aggregator provides valuable services in terms of summarizing and filtering data, and publishing it to the other elements in the architecture. Thus, the primary responsibility of an aggregator node is to collect data from the sensor network and publish it to various indexer nodes.

[0040] At step **301**, the aggregator receives sensor data from sensor-network gateways **28**. In particular embodiments, sensor nodes are dumb, constantly feeding data through their sensor-network gateways **28** to aggregator nodes **16**. In other embodiments, sensor-network gateways **28** execute a security policy as previously described. Regardless of the mechanism utilized by sensor-network gateways **28**, their sensor data is sent to one or more aggregator nodes **16**.

[0041] Initial data categorization and summarization occurs at step **302**. Because data from sensor networks is likely untagged and in the form of a real-time data stream, the aggregator node must first categorize and summarize the incoming sensor data. Sensors produce huge amounts of data. For example, phones may continuously generate data about location, light intensity, sound, accelerometers, etc. However it is not energy efficient (and might be very hard) to store and process the raw data. Thus data reduction may be important. An aggregator may use multiple mechanisms to achieve this difficult goal.

[0042] In particular embodiments, metasense queries may be used to categorize and summarize sensor data. A metasense table represents a collection of related data. Aggregator nodes **16** use metasense queries to collect all data meeting a particular set of specifications into a table. Metasense queries may be represented by a language which may then be converted into a graph. Multi-sensor data is fed into small graph/state machines to generate aggregate data. For example, a query may define a rule: {Output(1) every 10 s whenever Mean(lightIntensity)>100 and Median(sound frequency>1 Khz.}. This rule broken down into a decision engine with a mean block that tracks mean (running average) and a comparator. Collectively the rule, comparator, and decision engine may form a programmable logic block and multiples of the programmable logic block could run in parallel at aggregator nodes **16**, or alternatively, on the various sensor nodes **12**. If a query string has parameters that belong to a metasense table, then all the records related to that metasense can be provided as a result. Thus multiple complex data streams may be reduced significantly.

[0043] In another embodiment, aggregator nodes may use a standardized sensor data format to ensure summarization. Sensor data may be divided into two types: (a) data that reports environment properties, like temperature, humidity, pollen-level, sunlight etc., where a type/value format should be sufficient, and (b) data that reports non-property based information like text/audio/video data, where a type/value format may not be used. For case (a) above, this may be an alternative to using metasense. Providing the aggregator with an ability to use standardized property-based data may be useful in many ways: first, it provides a uniform and consistent way to represent data globally for all sensor nodes **12**, second, it provides a concise way to report/store data, third, it allows for easier indexing based on type, and finally, it allows for faster lookup for searches (for example, searching for a sensor data type). For non-standardized data, regular indexing is needed (based on header tag, frequency of occurrence of a keyword etc).

[0044] After the initial data categorization and summarization, data reduction is performed at step **303**. Data deduplication is necessary because of the sheer amount of raw data being transmitted to aggregator nodes **16** by the sensor networks. Generally, it is beneficial for data reduction to occur as early as possible; i.e., at sensor nodes **12** themselves, because reducing data transmitted by individual sensor nodes **12** translates into handling less data at subsequent stages.

[0045] For property-based data, an aggregator **16** may analyze incoming data and communicate with the sensor network to enforce suppression of redundant data. On a need-basis, an aggregator may broadcast a control message asking transmission suppression to ensure that sensor nodes **12** do not transmit redundant data in the first place. For property-based transmissions (where type of sensor-data is standardized), if a set of nearby sensor nodes **12** transmit the same data (which may often be the case), then only one sensor needs to transmit the data and other sensor nodes **12** should suppress their transmissions. To do this, all nearby sensor nodes **12** start by selecting a random time and setting a timer (that has a maximum bound). The sensor with the first timer expiration transmits the data. Other sensor nodes **12** listen to that transmission and register that a similar data has been transmitted to the sink (whether an aggregator node **16** or a sensor-network gateway **28**) and therefore, cancel their own transmission. Sensors do not have to do this by default. Aggregator nodes **16** may implement this reduction scheme in an adaptive manner. Initially, a sensor node should not use data suppression. The aggregator node may monitor the incoming data, and if it sees similar values from multiple sensor nodes **12**, it may send a control message in the network asking each sensor node to enable data suppression mechanism. In this mechanism, each sensor node listens to data broadcasts form other devices in a promiscuous mode. If a node finds that there are other sensor nodes **12** transmitting the same information, then it may trigger data transmission suppression.

[0046] In particular embodiments, the aggregator nodes may perform application-aware data compression: Aggregator nodes **16** may use application-specific data summarization techniques to drop redundant information from raw sensor data. This is not same as data compression; it is actually dropping redundant or useless information from ever being transmitted based on an application-specific mechanism. This task would simply be too computation-intensive to be executed by power-limited sensor nodes **12**.

[0047] More often than not sensor nodes **12** would not report any change in data, and for most reports, the same value would be reported. This value could be analog or digital text, audio, or video data. Hence, an application level redundancy checker is needed. A simple example of data in a video format is described below. Application-specific redundancy elimination is not limited to video data, for other formats, appropriate data patterns may be recognized and stored for compression.

[0048] Time: 0-1 hr: a tree in front of a building (Nothing happens)

[0049] Time: 1-1.15 hr: a cat climbs the tree and lounges for sometime

[0050] Time: 1.15-2 hr: the cat has left and the frame reverts back to the one in time (0-1 hour) phase.

[0051] The compression technique is simple: for every new frame, the aggregator compares it to the previous one; if it is same, then the aggregator drops it. Otherwise, the aggregator compares it against a set of frames stored in a dictionary. This step identifies if the video stream falls back to a previous state. If the frame is new (meaning it does not exist in the dictionary), then the aggregator adds the new frame to the dictionary. Using this mechanism, the aggregator is able to identify that, between 0-1 hour, the video feed is roughly the same frame, (for example, F**0**). From 1-1.15 hr, there might be K unique frames {F**1**, . . , Fn}. From 1.15-2 hour, the video feed reverts back to a frame substantially similar to frame F**0**. Hence, the newly created dictionary only needs to keep frames {F**0**, . . . , Fn} in storage. Thus, the actual content may be summarized as:

[0052] Time: 0-1 hour: F**0**

[0053] Time: 1-1.15 hour: {F**1**, . . . , Fn}

[0054] Time: 1.15-2 hour: F**0**

Where frames F are retrieved from the dictionary. The strength of this approach is that since decompression merely comprises dictionary look-ups, the decompression step is relatively fast. Also, this approach is different than LZ/Huffman compression since in this case, application context is used for summarization rather than raw data. During data display, this summarization may be used for an intuitive display. Each interval may use its beginning frame as a thumbnail:

[0055] Time: 0-1 hour: Thumbnail F**0**

[0056] Time: 1-1.15 hour: Thumbnail F**1**

[0057] Time: 1.15-2 hour: Thumbnail F**0**

When playing, the device may display frame F**0** for T seconds (a small time buffer to represent 0-1 hour, 10 seconds may be), followed by frames F**1**, . . . Fk, and then play F**0** for T seconds.

[0058] In particular embodiments, an aggregator may identify and reduce redundant energy-hogging data transmissions. The well-powered aggregator may look at various feeds and identify or verify if feeds from several sensor nodes **12** might be identical. The aforementioned techniques would allow the aggregator to detect redundancy for both property-based and non-property-based feeds. If feeds are identical, then, the aggregator may send a control message asking devices that are transmitting redundant information to pause sending identical data.

[0059] At step **304**, the aggregator nodes validate the data. Sensor networks as contemplated rely on accurate consistent data, and thus maintaining data integrity is of paramount concern. Thus aggregator nodes **16** may be able to detect malicious or erroneous data transmitted from rogue sensor nodes **12** or sensor networks. In particular embodiments, aggregator node **16** utilizes a Machine Learning for Anomaly Detection in Sensor Networks using (Spatial/Domain) Correlation Sensor algorithm. Such an algorithm is able to differentiate between a faulty sensor and a rogue sensor. An aggregator node **16** may use simple machine learning tools for such validation. For example, assume a temperature sensor is under consideration. A police sensor keeps track of distributions of nearby sensor nodes **12**. The temperature of a nearby sensor may not be arbitrarily different from the temperature gradient. The police sensor keeps the temperature distribution of its nearby sensor nodes **12** and records how the temperature drops off as a distance from itself. If a particular sensor X has different distribution parameters, it might be malicious with some probability which may be found through hypothesis testing. Upon detecting a malicious sensor, an aggregator node **16** could take several actions, ranging from jamming this sensor to ignoring the sensed values during in-network query processing.

[0060] At step **305**, aggregator node **16** formats the sensor data for processing. An aggregator node **16** may provide several key services that may add value to data in terms of future searches. Sensors are resource-constrained and may need service-assistance from aggregator node **16** (a power device connected to the Internet). Aggregator node **16** may, as an example, stamp data with the following attributes:

[0061] Data may be stamped with an accurate time (NTP) since individual sensor nodes **12** may not have an accurate clock.

[0062] Data may be stamped with the geographic location of the sensor node or aggregator node **16**. This will reduce search time in geographically-constrained searches. In order to make search and indexing more accurate, the gateway **28** or aggregator node **16** may also add text or anchor information for data using metasense capabilities.

[0063] At step **306**, aggregator nodes **16** append metadata to the received sensor data for the purpose of providing efficient searches. Aggregators **16** may also convert to text to be used by indexer node **26**. Sensors may send hints (for example, temperature data may be annotated with the property temperature), which aggregator nodes **16** use to generate metadata tags. The metadata tags may be dimensions in a multi-dimensional array for efficient search by indexer nodes **26**. For audio data, aggregator nodes **16** may utilize speech-to-text algorithms to generate metadata. Similarly, for video data, image analysis may be used.

[0064] Aggregators **16** may use one or more tags (such as for example sensor IDs) to determine that sensor data is related to a particular sensor subject, and add the sensor subject to the metadata. As an example and not by way of limitation, aggregation system may receive one or more data sets from one or more sensor nodes **12**. Sensor data in the data streams may include or have associated with it tags identifying sensor IDs of sensor nodes **12**. Aggregators **16** may determine a sensor subject related to the data streams by querying the sensor IDs to a suitable record (such as for example a lookup table or index) indicating the sensor subject associated with the sensor IDs.

[0065] Aggregators **16** may also provide encryption, secure session with indexer nodes **26**, firewalls, and other network components to maintain the sanctity of the underlying network as it acts as one entry point to the network. In particular embodiments, aggregator nodes **16** may perform a data integrity function on one or more data streams, such as for example by encrypting the data, using digital certificates, having the data authenticated by a third-party system, or by using trusted data collectors, wherein the sensor data is generated and data integrity is maintained through limited APIs to access the database.

[0066] For sensor data from private devices like cellphones, PDAs, tablet PCs, and the like, aggregator nodes **16** should support anonymizing the data before it is sent out to indexing layer **204**. In particular embodiments, any sensitive data that may be used to uniquely identify the generator node may be stripped off and not recorded, or summarized, or given access to in a live stream. In particular embodiments, data-aggregator nodes **16** may anonymize one or streams of sensor data, such as for example by removing information from a data stream that identifies (directly or indirectly) one or more of the subjects associated with the data set.

[0067] At step **307**, aggregator node **16** appends time-stamps to the aggregated sensor data, if time-stamps are not already attached to the data. In particular embodiments, time-stamps are merely a special metadata tag. In particular embodiments, time-stamps are a special property of the data used for indexing. In particular embodiments, time-stamps may be added by both sensor nodes **212** and aggregator nodes **216**.

[0068] At step **308**, aggregator node **16** transmits its aggregated sensor data to indexing layer **204**. This transmission may either be directly to an indexing node, or through multiple hierarchical layers of aggregator nodes **16** to an indexing node. Aggregator nodes **16** may use both push and pull models to transmit their data to indexer nodes **26**. In the push model, aggregator node **16** collects information and periodically submits data in a batch to an indexer node **26**. In the pull model, indexer node **26** queries indexer node **26** and requests for additional information beyond the previous batch (or batches) of information. The need for pull may be either because indexer node **26** needs additional data for a particular event beyond the provided summary, or because indexer node **26** needs a real-time input for a particular event. In particular embodiments, aggregator node **16** determines what data needs to be shared with the indexer-based on interests communicated by the user-queries from indexer **26**, or based on popularity or relevance of the data. In particular embodiments, aggregator node **16** publishes necessary feeds to upward indexing engines using a distributed publish-subscribe (pub-sub) architecture. The architecture is hierarchical and at each level of hierarchy there are aggregator nodes **16** that present more collective statistics, and indexer nodes **26** look for time-based measurements and various sensor network toolboxes to determine if the sensed data is statistically significant. In particular embodiments, aggregator node **16** may also register with the search-query layer **205**, and proactively identify services available with it.

[0069] Each aggregator node **16** also maintains a reliability index for use by indexer nodes **26**. Each aggregator node **16** maintains a list of sensor nodes **12**, their locations, capabilities, and most importantly the trust in the sensor. In particular embodiments, aggregator node **16** determines the owner of a particular sensor, and accesses a database of highly reliable organizations, such as CNN for news, the Weather Channel for weather, etc., to determine the trust level of a particular sensor or sensor network. In another embodiment, the system utilizes a self-correcting marketplace where information is selected on a weighted average system of all information available from a dense set of sensor nodes **12**. The weights reflect a property of the sensor data, such as the quality and reliability of data. Thus, in particular embodiments, if two sensor nodes **12** provide the same data, but one provides a higher quality, aggregator node **16** assigns a higher weight to sensor node **12** that has higher quality data.

[0070] Indexers communicate with aggregator nodes **16** or other indexer nodes **26** on a frequent basis. Efficiency is increased through the use of adaptive, medium-lived TCP tunnels for faster data transport. Transporting massive sensor data over the Internet may need a customized transport solution to make it faster, reliable, and efficient. UDP may not be used since it does not have reliability, congestion-control, and flow-control. Without these controls, the Internet would run into congestion problems, and the receiver would run into the problem of receive buffer overflow. Thus, in particular embodiments, aggregator nodes **16** use TCP as a control protocol for communications with indexing layer **204**.

[0071] One particular embodiment uses medium-lived TCP tunnels. Indexers run a modified version of TCP to retrieve data from aggregator nodes **16**. Since aggregator nodes **16** send data for various requests, each aggregator node **16** may create an application running on top of TCP, and instead of closing the TCP connection, as in HTTP, keep the TCP connection open for T(t) duration, relying on the high likelihood that there would be request for sensor data in near future. T(t) may be adaptive; if network resources are low, then T(t) is decreased. If network resources are plentiful, T(t) is increased.

[0072] However, even with such an adaptive window, indexer **26** might become overloaded with a large number of lingering TCP connections. In particular embodiments, indexer **26** may take three possible actions to avoid overload. First, it may specify a maximum limit on the number of tunnels. Second, if it gets starts to approach this limit, then it may close connections that have relatively fewer requests. Third, for the case where aggregator nodes **16** may crash without gracefully closing TCP connection, indexer **26** may set TCP keepalives to clear lingering TCP connection. Application-based modifications will allow TCP connections to avoid the overhead of establishing connections (extra packets in the Internet and the delay associated with it). One advantage to keeping the connection open is that the connection may use the last congestion window and avoid the costly TCP slow-start. Traditionally, all new TCP connections start at a very low data rate ("slow start") and thus, the data is not sent at a suitable transmission rate. But, in this embodiment, retaining one TCP connection would mean avoiding frequent connection overhead and avoiding the initial low data-rate.

[0073] Indexer nodes **26** have the responsibility of organizing and indexing input sensor data from a list of aggregator nodes **16**, so that when an end-user issues a search, indexer **26** may more easily efficiently do a look-up and return relevant data entries. Indexer nodes **26** collectively form an overlay search network that routes end-users search requests and data. Indexer nodes **26** may route queries between them, and ultimately route requests for data from end-users to the sensor network where the desired information is available.

[0074] Once data is collected by aggregation layer **203**, characteristics of the data are identified by indexing layer **204** and metadata related to sensor data is stored in efficient data structures for future query search. In particular embodiments, indexers may form an overlay with each other, where they may communicate and transfer data of common interest. Queries from the end-users are routed to indexer nodes **26**. Indexers form an overlay nodes for query routing from the end-users to the sensor network where desired information is available. Each indexer node **26** stores multiple data structures for all the sensor data available to indexer node **26**. The data table or data structure contains one entry for each connected sensor network that wishes to share its data with the outside world. Each indexer node **26** is assigned geographical coordinates. An example data entry for a sensor network is described below:

[0075] Sensor-Network Gateway Address: Each connected sensor network is identified by its sensor-network gateway **28** address

[0076] Physical/Logical coordinates of the source of data available from a desired sensor network

[0077] Address

[0078] Data Matrix: A matrix storing a data type and its attributes, for example: (a) Data Type 1, size per entry, raw or processed data, quality, time-duration; (b) Data Type 2, size per entry, raw or processed data, quality, time-duration

[0079] Access List: Each sensor-network gateway **28** may enact a security policy, and indexer nodes **26** may store an access list that determines if data access needs to be restricted to certain end-users.

[0080] In some embodiments, each sensor network may update their entries in neighboring indexer **26** periodically or on-demand if desired. Once entries are updated in indexer nodes **26**, then indexer nodes **26** may communicate with each other periodically to sync their entries. In particular embodiments, all data that is not meant to be shared is stored within a sensor network domain. Data that needs to be shared may be stored at sensor-network gateways **28**, or a dedicated data repository specific to each sensor network, which may be accessed by the outside world. In other embodiments, data may be stored for offline access and may be kept outside the sensor network domain after implementing necessary security policies. In such an embodiment, indexer nodes **26** will have the information available about the offline data location. For real-time data access, queries need to eventually delivered to the actual sensor-network gateways **28** to access real-time data.

[0081] FIG. **4** illustrates an example method for indexing sensor data. At step **401**, indexer node **26** receives data from an aggregator node **16**. Indexer node **26** may receive the data from aggregator node **16** in response from a request for data, or indexer node **26** may have previously subscribed to all or a portion of the data aggregated by an aggregator node **16**, after which aggregator node **16** actively pushes data up to indexer node **26**. The primary difference between traditional indexing and indexing for sensor streams is that the data in the stream has much lower significance compared to the metadata. Therefore, the metadata is indexed, rather than the real data, because by the time the query comes, the data in the streams would have changed, but metadata has much more hysteresis and hence changes much more slowly than the real-data. Indexing real-time streams, although similar to real-time search, differs due to the streaming nature of the data. In particular embodiments, data is conveyed as a time series, using popular models such as autoregressive integrated moving average (ARIMA).

[0082] At step **402**, indexer node **26** analyzes the incoming aggregated sensor data. The sensor data has already been tagged with metadata from aggregator node **16**, and undergone basic summarization and classification. Various embodiments contemplate several different mechanisms for generating indices for the sensor data. In particular embodiments, data streams may be summarized by collecting the signature of the flow. In another embodiment, indexer node **26** may specify a data storage format, such as, for example, (<data type> <size per entry><raw or processed><quality><time duration.>). In particular embodiments, indexer nodes **26** employ parallel architectures such as the systolic array; each small processing unit may index independent entities. In another embodiment, a TCAM like structure may be used to perform parallel and potentially single clock cycle lookup through the index.

[0083] At step **403**, indexer node **26** generates keywords for each received sensor data stream. In particular embodiments, indexer nodes **26** use metadata added by aggregator nodes **16** as keywords describing the stream. Every stream is summarized and annotated by keywords, which indexer node **26** uses as anchor keywords for inverted indices. Aggregator node **16**, or, alternatively, indexer node **26** itself converts a stream into a bag of keywords based on meta-sensing classifiers. For example, if the stream is near static, indexer node **26** adds the keyword “static” to the bag of keywords for the stream. If the stream varies significantly, indexer node **26** adds the “fluctuating” keyword. For different domains, classifiers may work on this streaming data and convert it into words. Indexer nodes **26** classify the streams into keywords in a parallel fashion, and the classifiers could be described flexibly using business logic language and implemented in hardware, in parallel.

[0084] In particular embodiments, indexer nodes **26** maintain keyword frequencies by combining keywords for different time windows, thus forming a true keyword frequency distribution. Since each keyword is a single dimension, indexer node **26** may further summarize the stream by the eigenvalues in the keyword space.

[0085] At step **404**, indexer nodes **26** generate indices and keywords from the metadata for each piece of accessed sensor data. In particular embodiments, indexer nodes **26** may use metasense queries for efficient indexing. For example, if a query string contains parameters that belong to a metasense table, then all the records related to that metasense can be provided as a result. An index generated for a data stream that is, itself, generated by metasense commands would create a multidimensional array including the conditions and criteria of metasense commands. For example, when indexing a stream of data generated in paragraph **42**, the index could include a multidimensional array, wherein the array values are, for example: (<periodic><every 10 seconds AND Mean (lightIntensity)>100 AND Median(sound frequency>1 Khz. }). Thus metasense queries are easily matched with the data generated by metasense queries.

[0086] In particular embodiments, data may be indexed based on the properties appended to the data during the initial categorization/summarization by aggregation layer **203**. Thus data may be indexed as property/non-property based data, and further, with property based data, by the data's type value or format. For non-property based data, the data may be indexed by the standardized metadata appended to the video or audio stream.

[0087] In order for indexer nodes **26** to efficiently generate searchable indices for sensor data streams, the data must be tagged and summarized by aggregator node **16**. It is possible that the data being fed from an aggregator nodes **16** does not have necessary time-stamp, geo-tagging, or text-tagging. In particular embodiments, the indexer node verifies the incoming data and sends a control message to aggregator node **16** asking it to start providing data stamping. Similar logic applies for application based data summarization. An indexer node **26** may communicate with aggregator nodes **16** to enforce data summarization

[0088] In particular embodiments, indexer nodes **26** may also generate indices for data based upon the reliability index of the sensor network. An aggregator node **16** maintains a trust level for each sensor based upon the owner or a "trust marketplace" as previously described, and indexer node **26** may respond to queries specifying only a trust level at, above, or below (though unlikely a query would be generated seeking untrustworthy sensor data) a specified trust level. The reliability score may be based on a variety of criteria, such as for example time lag, sampling rate, sensor reliability, sensor sensitivity, sensor type, sensor location, sensor subject type, prior history of the seller of the sensor data, a combination of two or more of these criteria, or other suitable criteria.

[0089] Particular embodiments include sensor-data redundancy for TCP connections between an aggregator node **16** and an indexer nodes **26**. A set of data transmitted from aggregator node **16** to indexer node **26**, called a data page, is marked by aggregator node **16** with an identifier called a short index. An aggregator node **16**/sender maintains a mapping of data sent to a short index, and may determine that, if it is simply sending periodic data matching the previously sent data page, aggregator node **16** may send only the short index. Indexer node **26**, upon receiving the short index, knows that the data page is already stored at indexer **26**. This is known as DRE and multiple variations of DRE customized for sensor networks may be envisioned by those of ordinary skill in the art.

[0090] FIG. **5** illustrates an example method for generating a sensor-data query. Search-query layer **205** is responsible for receiving a query from an end-user or application and generating a properly formatted query that aligns with the indexing performed by indexing layer **205**.

[0091] At step **501**, a user issues a query to search engine **22**. In particular embodiments, there are two ways query may be specified. First, query may be made through web search engine interface that enables query specification in a standardized format. Second, any two sensor networks may exchange data by querying each other by formulating query using standard APIs. A query may be sent on demand, or periodically as per the end-user requirements. In particular embodiments, end-users prepare a request for the desired data with following key attributes:

[0092] Type of Data Requested: Sensors streams are multi dimensional. Hence the query specifies which of the available dimensions it is interested in. For example, different sensor networks may monitor multiple environmental properties. The type of data determines different properties (temperature, humidity etc.) that are requested by the query. Standard techniques for data dimension reductions like Principal Component Analysis (PCA) may be applied for data size reduction and hence, a faster search. Standard PCA techniques are envisioned by this disclosure, including approximating a data matrix through the use of eigenvectors corresponding to the top eigenvalues of the matrix. In particular embodiments, there are two modes in which query request may be made: a search mode and get Mode: The search mode determines that end-user is searching for the indexer that has data availability information. Get mode determines request to be delivered to the final source of the data selected by the end-user.

[0093] Raw Time-Series Data or Processed Data: A user might query for the real-time data stream or the processed data depending on the need. Processed data may be a temporal or spatial average, some kind of metadata, or any other combination. Particular embodiments may include a toolbox that may perform very fast hardware assisted statistical aggregations on data streams. In particular embodiments, statistical aggregations occur offline and are cached. In another embodiment, the statistical aggregations are generated run-time based on the user query. In particular embodiments, popular aggregations or processed data are stored locally on indexer nodes **26**.

[0094] Streaming, Periodic, or One-Time Data Request: This attribute determines if the end-user needs streaming data, is requesting a periodic update of his query, or is requesting a one time result for his query. Specifying this ensures that the query and the results are updated as per user specification. For example, if a user desires periodic update, he/she could alternatively transmit the query periodically in order to get the search results, or, once the user has chosen the search result, the user might want to specify in his or her query that the user desires a periodic update from the same source.

[0095] Timeliness of the Data: In particular embodiments, this attribute has three possible values. The first value provides the most recent data available or (t=Tpresent), a second value specifying historical data with time range (Data between Time T **1**<=t<=T**2**), finally a third value provides future data with time range (Data from Tpresent<=t<=Tmax). In particular embodiments, the third value is the means by which a user makes a request for streaming data.

[0096] Location of Sensor Network: In particular embodiments, a query may include a request only for data near a specified location. The location may be specified with logical coordinates, i.e., address of the sensor-network gateway **28**, or with physical coordinates of the sensor-network gateway **28** or sensor nodes **12**. In particular embodiments, the query may include an operator that provides a "best match" option: this option may be used when location of the data is not known.

[0097] In particular embodiments, the user may issue queries that do not require raw time-series data, but instead need information on specific interesting events that may happen in the sensor network. For example, a user might be interested in lightning strikes, but there is no standard query container for identifying a lightning strike. Therefore, he may seek video data when light intensity is recorded above a given threshold and is followed by sound intensity above a given threshold within ten seconds of the light intensity spike. These conditions could be formatted into a metasense query and passed to indexer nodes **26**.

[0098] In particular embodiments, the users are provided with a set of application program interfaces (APIs) for query specification. A set of APIs are defined that are used by end-users to specify query for the desired information. These APIs would allow applications to directly query or to automate querying of data from various indexer nodes **26**. For example, pseudo-code for functions prepare_query_Request( ), send_query_request( ), and receive_query_response( ) could be used by various applications, such as applications in a mobile phone, GPS, or other computing device, to generate and send queries or receive results.

[0099] At step **502**, search engine **22** accesses a cache of popular queries. In particular embodiments, indexer nodes **26** may collectively maintain a cache for recent popular queries. In another embodiment, search engine **22** itself maintains the cache of recent popular queries.

[0100] At step **503**, if search engine **22** determines that input query matches a set of recent popular queries, then search engine **22** may suggest those queries to the end-user. In particular embodiments, the queries may be presented in an ordered list. In another embodiment, they may be presented in a drop-down menu.

[0101] At step **504**, if the user finds one of these queries a near-perfect or perfect match, then the user may choose the closest query. In particular embodiments, the user makes his selection through a pointing device. In another embodiment, the user makes his selection via a touch input. In another embodiment, the list of cached queries includes an option indicating that none of the suggested cached queries match the user's query. Indexer nodes **26** maintain an updated compilation of search results for some of these popular queries and serve the results to the end-user, largely reducing lookup delay. In another embodiment, search engine **22** itself maintains the updated compilation of search results for some of the popular queries. If the user selects a cached query, search engine **22** proceeds automatically to step **508**. If a user does not select a cached query, then search engine **22** proceeds automatically to step **505**.

[0102] At step **505**, search engine **22** performs query translation from the text entered by the end-user to a format matching the indices generated by the sensor data. The translation process essentially converts the text and options selected by the user or API into a format which may be read by indexer nodes **26** within indexing layer **204**. Techniques for this conversion process are well-known in the art. For example, a user may select one or more, but not all, of the data criteria described below. The user may make these selections through the use of drop-down menus, GUI buttons, and text fields for searching the sensor network. Search engine **22** converts these inputs into a query string or instruction conveying the user selections in a compact format that is understood by indexer nodes **26** within indexing layer **204**.

[0103] At step **506**, search engine **22** determines whether the user has requested sensor data from a specific sensor or sensor network. In particular embodiments, the user, through either the search engine or an API, may append a query with an option unique resource identifier. Every sensor network has a unique resource identifier, including but not limited to and IP address or unique name. The user has the option of including the resource identifier along with the query. Thus, get-based queries with an option unique resource identifier are directed to the specified sensor network, and an end-user may retrieve the desired data, whether real-time or stored, directly from the specified sensor network. In another embodiment, the user may browse a directory type structure to determine the list of publicly available sensor networks or if a sensor network is restricted, and filter the resulting list of matches to show only those sensor networks that should be visible to the user in addition to the publicly available sensor networks. In another embodiment, the user may specify a particular sensor or sensor network with a search engine GUI, and search engine **22** creates the option unique resource identifier. At step **507**, the option unique resource identifier is appended to the query. At step **508**, the translated query is transmitted to the overlay-search network provided by the network of indexer nodes **26** in indexing layer **204**.

[0104] FIG. **6** illustrates an example method for retrieving sensor data in response to a sensor-data query. In particular embodiments, an indexer-based overlay search network employs various mechanisms that are optimized for responding to a search query. Search engine **22** performs smart prefiltering, and then designs a cascade of filters that progressively reduce the search space. Alternatively, the indexer-based overlay search network may perform the prefiltering and filtering. At step **601**, indexing layer **204** receives the translated query from the search-query layer **205**.

[0105] At step **602**, the overlay search network performs prefiltering of the sensor data that may be returned to search engine **22** in response to the translated query. Prefiltering may be based, but are by no means limited to, the following

[0106] Geographic Security Regulations: Sensor streams may be omitted during the prefiltering and ranking process based on a security policy. For example, government regulations may prohibit allowing anyone from Asia access key energy data streams. Thus, the geographical location of query entity is important and may be used to prefilter candidate streams.

[0107] Robustness Against Off-Path Attacks: If the user who is running the search requires some form of lightweight security, search engine **22**, indexing layer **204**, or user equipment may generate a temporary password and communicate that with indexer node **26**. Indexer node **26** uses the password to provide a lightweight encryption when sending the results back to the user. Thus off-path attacks against some malicious user trying to inject bogus results into the query results are avoided.

[0108] Secure Connection for Subscribed Services: In some embodiments, access to certain streams of sensor data requires a paid subscription. In such an embodiment, indexer node **26** stores user information and its password; the password is be used for providing a stronger encryption (e.g. TCP MD5 connections).

[0109] At step **603**, the overlay search network generates filters in accordance with the requirements of the translated query. Examples of some filters designed to reduce the data results are described below. This disclosure is by no means limited to the listed filters, and contemplates any number of varying types of data filters.

[0110] Similarity Search: For a query specifying a data distribution D, find all sensor nodes **12** that have sensed data distribution similar to D, and have tags given a search tag set S. Data distributions may be temporal (i.e. based on values occurring from time=t**1** to time=t**2**) or may be a running average (long term) based on policies and search options. For example, a user might want all sensor nodes **12** that are of type smart meters, and of type GE (made by GE) that have a voltage distribution D. In such an example, the filter designed would include search tags "GE", "SMARTMETER" and a data distribution D. The data is first reduced to a list of probables by prefiltering in the tag space, giving rise to several candidate sensor streams CS. The query system then calculates a distance metric dist(D,D_s, metric) for each data stream in CS. In particular embodiments, the metric is a KL distance. In another embodiment, the metric is a Euclidean distance. In another embodiment, the metric is a Mahalanobis distance. The distances for each sensor stream are then fed into a ranking engine.

[0111] Range Search: Filters are designed based on constraints on the ranges of attributes, and may also have distributions and keywords. In particular embodiments, indexer nodes **26** maintain spatial data structures like R trees. For example, search queries based on geographic location and radius require sensor nodes **12** to be filtered out based on their location and the query ranges in latitude, longitude, and, optionally, radius.

[0112] Query Filters Generated on the Basis of Rank, Search Reputation, and Popularity: Query filters may be designed based on quality of the data. Data quality is determined by a composite score based on several attributes: (a) rank, (b) search reputation, (c) popularity (the number of other users accessing the data), (d) history, (e) spatial correlation with nearby sensor nodes **12**, and (f) sensor owners and their attributes (based on policy).

[0113] Using Meta-Sensing and Annotation to Generate Search Keywords: As previously described, aggregator nodes **16** or indexer nodes **26** convert input data streams into keywords based on meta-sensing mechanisms and appended annotations. When a query is triggered, logic translates the search query into the same set of keywords so that the query may be quickly mapped to the final search data.

[0114] Categorization of Input Query (Raw Time-Series or Processed Data) to Provide Easy-to-Read Query Results: Queries may be of different types a) a user may ask for a query to be a distribution, b) time series, c) summarized time series, or d) any of a) b) or c) further augmented by attributes, tags, keywords. The response identifies the categories of data required by the query, and searches the database to respond accordingly.

[0115] Learning User Preferences: In particular embodiments, indexing layer **204** may collectively learn the preferences for the user and build a profile for that user. The profile may consist of a set of keywords with a weight assigned to each. If the input query is not completely accurate, the above profile may be used to provide a more relevant response. Individual elements of this profile may be updated on a regular basis. In particular embodiments, an exponentially weighted moving average (EMWA) is used to advance the profile. Essentially, as a keyword "T" is advanced in the user profile, a large fraction from the history is kept, and a small fraction from the current search query is added. In other words, New Average of T=alpha*(Previous Average of T)+(1−alpha)*(Weight of T in the current Query). If alpha is a large value, for example, 0.90, local fluctuations in the profile may be avoided, and changes in keywords may be gradually implemented into the profile.

[0116] Using User-Location to Influence Response to a Sensor Query: In particular embodiments, the search-query layer **205** or the indexing layer responds to queries based upon the location of the user. The search-query layer **205** may add user location to improve the relevance and ranking of the query results. In case of certainly, the default user location may be utilized to present relevant results. For example, if the user enters "local temperature", the latitude/longitude of the user's location may be used to present accurate temperate at the top of the results list, followed by results from other sensor nodes **12**. In the absence of any other more relevant criterion, location is used to respond and provide results.

[0117] At step **604**, the overlay search network applies the cascading filters to the sensor data generated by system **200**. When indexed sensor data matching the query criteria are found at a particular indexer **26**, the data is considered a "match." Indexer **26** indicates the sensor location and other relevant information regarding the match.

[0118] In particular embodiments, some query results are served by cached data. For example, a query requesting the average temperature of Arizona in summer may be served by purely cached data; there is no pressing need for a real-time data stream in such a query, in fact, a real-time data stream is insufficient to meet the query criteria. Of course, some queries may not be served by cached data, such as the average temperature today. Essentially, real-time queries may not be served by cached pages.

[0119] Regardless of whether the result is real-time or cached, step **605**, indexer node **26** with the matching data transmits the result back to the search-query layer **205**, or, alternatively, to indexer node **26** from which it received the query.

[0120] In other embodiments, the overlay search network, comprising the plurality of indexer nodes **26**, perform various other functions to optimize the system **200**. For example indexer nodes **26** may use search feedback to ensure high-quality data. In particular embodiments, the search-query layer **205** utilizes search feedback to adjust elements of sensor infrastructure. The search feedback is used to adjust resource allocation for sensor networks and aggregator nodes **16**. Sensor networks typically use lossy wireless links and have limited battery power; if it is determined that some query has become popular and that the sensor network providing data needs assistance, then, depending upon the query result, feedback is transmitted to the relevant network.

[0121] In other embodiments, indexer node **26** analyzes the query results and provides the search feedback. If an indexer **26** analyzes that a given set of queries have become popular and if the sensor network that ultimately provides data needs assistance (in terms of battery power or better bandwidth), then depending upon the query result, it could provide a feedback aggregator node **16** and aggregator node **16** may forward it to the relevant network. For example, if the query has become popular for a particular video sensor, and if the video quality is poor, then the search-query layer **205**, or, in some embodiments, indexer nodes **26** provide the feedback. Or, if the sensor network is running out of battery, an alert to aggregator node **16** of that network is triggered.

[0122] In other embodiments, indexer nodes **26** employ a power saving mechanism. For any real-time query, a given sensor may stop collecting data based on the queries. If a sensor receives a notification that there are no subscribers to some or all of the sensor data supplied by the sensor, the sensor may go to a power-save mode. For example, for security cameras, unless a RTSP streaming session is started, a camera does not produce a stream, so the encoder may be in a power save mode. The moment a query is sent to the streaming server and user selects the link, a session is created and the sensor starts producing the data stream. Thus, as connections are torn down, a individual sensor, or an entire sensor network, may enter power saving mode.

[0123] FIG. **7** illustrates an example method for presenting sensor data retrieved in response to a sensor-data query. In particular embodiments, the display of search results is carried out by search engine **22**. In another embodiment, the display of search results is performed by indexing layer **204**. In another embodiment, the presentation of search results to the end-user employs processing in both the search-query layer **205** and indexing layer **204**.

[0124] At step **701**, the search-query layer **205** receives a list of matching data from indexing layer **204**. Alternatively, indexer node **26** receiving the query may obtain this list of matching data from various lower level indexer nodes **26** within Indexing layer **204**.

[0125] At step **702**, a stored user profile for the user issuing the query is accessed. In some embodiments, the search engine or the indexer-based overlay network may store a user profile for specific end-users, and tailor the ordering of their search results based upon their stored user profile. This is similar to a personalized search; one particular user might prefer one stream over the other, and the query system or indexer nodes **26** record this preference in the user's profile If the user runs the same query again, his history will be recalled and the stream picked the last time will have a higher ranking Similarly, this history may be leveraged to build a user-profile and match the final results with the user-profile to ensure that result representation is closer to what a user would expect.

[0126] In another embodiment, the user profiles are maintained collectively by indexer nodes **26**. This database may assist indexer nodes **26**, and in turn, aggregator nodes **16** in ensuring that if they use any caching, then the weightage of elements in the caching may be adjusted by the user and query profiles. For example, if there are relatively more users who are interested in looking up at traffic condition for a given aggregator node **16** (representing an area), then that aggregator node **16** may use this information to maintain a cache of this information (instead of sending a query to the sensor network on a regular basis).

[0127] At step **703**, after accessing the user profile, the search-query layer **205**, or alternatively, the indexer-based overlay network sorts the results list in order of relevance to the particular user issuing the query. Multiple metrics are envisioned by the disclosure for the scoring of results. When indexer **26** presents multiple records as possible results to a query, the search-query layer **205** ranks the list of results based on certain metrics:

[0128] Available Data Type: in particular embodiments, results are ranked based on number of types of data available. For example, if there are two sensor streams outputting traffic speed stream data, and one of them has an associated video feed, then the one with the video feed might have higher relevance.

[0129] Real-Time Nature: in another embodiment, the importance of real-time data to the query is assessed and the query results scored based on which data streams best match the temporal requirements of the query. Time lag to a user might be different based on the query origination, and hence relevance will differ for the same query to different users.

[0130] Location: in other embodiments, if there are two result entries with similar relevance in terms of data type, real-time nature, history, the user's location may be utilized to determine which result should be displayed to the end-user first. This method is of particular use in the case when a sensor data is tagged with geographical location.

[0131] Result Popularity Index: in other embodiments, indexer node **26** utilizes a lightweight mechanism to mark search results in terms of their popularity (a popular search result is one which is being read by a lot of users). When a query is triggered and indexer node **26** finds that some of its results belongs to the set of popular results (news), then it may tag it with a popularity index. When presenting two entries for the search result, all other metrics being equal, then the result which is more popular may be presented first.

[0132] Furthermore, in other embodiments, the sensor data stream results may be ranked based on how any metric correlates with other metrics.

[0133] Data Dimension: in other embodiments, data streams with higher dimension will be given a higher ranking For example, the output of a temperature query might be 2 streams, one with temperature data only, the other with temperature data, wattage used, a heat map, etc. Since there are more correlated data in the second stream (which may be used to further process the raw temperature data), it will get a higher ranking.

[0134] Frequency of Data: in other embodiments, data streams with a higher frequency are automatically displayed earlier in the list of matches displayed to the end-user. Higher frequencies of sensor data updates generally correlates with greater data granularity. Therefore, the ranking of data streams with a high frequency of data updates is elevated when compared to less-frequently updated data streams.

[0135] Reputation of Stream Originator: in other embodiments, the reputation of the stream originator determines its placement in a result list relative to other matches. The reputation of a stream originator is a function of multiple parameters, such as a database of sensor providers, the number of subscribers to the sensor stream, the number of queries served by the sensor, the consistency nearby sensor nodes **12**, and the like. Exemplary factors determining the composite reputation score are described below.

[0136] User Feedback: in other embodiments, a user-based review system collects user assessments of the quality of the data from a particular sensor. Such a database may be stored by the search or query system or alternatively, indexing layer **204** itself. In some embodiments, the provider of the search-query layer **205**, or alternatively, a third-party, provides the sensor rating system. In addition to search, users may browse categories of networks that provide a specific sensor service and choose to subscribe or follow the one which has the best review.

[0137] How Many Subscribers to the Stream: in some embodiments, indexer node **26** adds ancillary information to the indexed entries for each sensor network.

[0138] Stream Source: In other embodiments, the source or owner of a stream may affect the reputation score of a stream of sensor data. For example, streams that are owned or operated by government agencies may have their reputation boosted.

[0139] Type of Data: In particular embodiments, the data type affects the relevance of a query result to the query. For example, from the data type, the system may determine how real time the data is. For example one stream might be from a private party, but an equivalent government sensor network might have a 30 second lag, which might be unacceptable to the application. In such a case, data type would take precedence over sensor owner reputation.

[0140] The search-query layer **205**, or alternatively, the indexer-based overlay search network may implement multiple methods for testing to determine the relevance of a presented result. These methods include but are not limited to: statistical testing (to determine statistically significant candidates, t-tests, ANOVA, etc. Particular embodiments determine baseline null hypotheses to determine the quality of search results. Once all these tests are done, the system calculates a composite score for each candidate query result. In particular embodiments, when forming a composite query, the system may assign weights based on targeted ads. For example, if a particular sensor stream is promoted with some advertising, then that sensor stream may be assigned a greater weight so that it appears earlier within the search results.

[0141] At step **704**, after ordering the list of search results by relevance, the search-query layer **205** presents the results to the user through an Adjustable Multi-panel Result Display. The adjustable multi-panel result display may be rendered on a user display at a personal computer or other network-connected device. In particular embodiments, the multi-panel result display is rendered by the web server of the search provider. In another embodiment, the multi-panel result display is rendered by a dedicated search application running on a computing device such as a tablet or mobile phone.

[0142] The result may be rendered in several panels on the same page. The number of such panels (a square area on a displayed browser page) may be adjusted by the end-user. The result rending engine is configured to provide various panels, for example, general, news, media, popular, education, traffic, and the like. The end-user is given the option to add panels to the page. For example, if the user adds a "general" panel and a "traffic" panel, the result would divide the main page into two half-pages, either horizontally or vertically. At step **704**, the search-query engine accesses a stored user profile and determines which panels the user has configured to display on his or her Adjustable Multi-panel Result Display.

[0143] At step **705**, the system assigns each individual result in the ordered results list for rendering in one of the panels of adjustable multi-panel result display. For example, if the user issues a query then all the results pertaining to traffic would sit in the traffic panel and all the remaining results would sit in the general tab.

[0144] Finally, the results are rendered within the individual panels of the user's adjustable multi-panel display at step **706**. In particular embodiments, smart pre-caching may be used to leverage faster response times when serving a query. For example, when a user queries for a particular data stream, the search results may display a link to the unique resource locator to the sensor data, and in the background start setting up the session for those links so that by the time the user clicks to subscribe to a stream, there are no additional latencies associated with session initialization. Such techniques are used by web pages to show images/videos

[0145] In particular embodiments, the search-query layer **205** uses a location (URL)/property shortener. Since the amount of information displayed with each sensor result could be large, the query and search engine may shorten the URL of a sensor network location, and associate it with property specific to the sensor networks. This service may be provided by a third-party, and operate in a similar fashion to that of bit.ly or tinyurl.com, but is differs in that the system, in addition to crunching the URL, takes the user directly to the service, stores data type, location, and various other services associated with the service. Clicking on the shortened location URL directly takes the user to the service offered by the sensor network and not the HTTP page for the sensor network. In another embodiment, ancillary information may be displayed in multiple ways. As an example, if user rolls his or her mouse cursor over the URL, then the web page displays the relevant properties of that sensor network in a tab.

[0146] In another embodiment, when a sensor stream is presented, the query-search layer **205** will output the number of subscribers to the source as a measure of the 'strength' of the source. The system may also present a time variance of the distribution of this list, just so that the sensor stream is not caught at an off-peak hours. The strength may be presented as a simple color bar ranging from red to yellow to green as a visual representation for quicker understanding of strength.

[0147] In other embodiments, the user is provided an option, after running a predetermined number of queries, to mark some sources as favorites. If these sources subscribe to other sources, the user is given an indication of the source's new subscription when presenting search query results. In another embodiment, when well-known sites, such as CNN or BBC, subscribe to a stream, an indication is shown as an icon by the side of the result. In another embodiment, the search engine is coupled to a number of social networking sites; if the user has friends in a social network that subscribe to some sensor streams, the subscribed streams are marked in the output to guide the user.

[0148] In another embodiment, the search engine provides functionality to allow an end-user to flag sensor networks as malicious or inappropriate. "Flag as in-appropriate" is a well-known mechanism to sift through bad websites. This mechanism differs from the user rating system as described above, in that a user is claiming that the stream is malicious or might be installing spyware and such, as opposed to posting a subjective rating of the data quality. Such streams may be handled through something similar to a phishing filter.

[0149] In another embodiment, the system utilizes a search API for subscription-based searches. Traditionally, searches are monetized through advertisements; it would be unprofitable for a search engine to provide a search API that does not allow advertising. However, if a particular service permits a user to pay for a subscription to access data, where a user is interested in monitoring, interacting, etc with a set of sensor networks, then indexer nodes **26** may also provide a search API, where the results of a query may be provided in the form of a text file. In particular embodiments, the user triggers the API by specifying keywords, number of pages and a file where the search engine would dump all the results. An example of pseudo-code is provided below:

[0150] file=open("users/foo_name/results.txt");

[0151] num_of_pages=100

[0152] sensor_search_api(file, "traffic on interstate 80", num_of_pages)

[0153] Since this results (being in a format of a text file) may be parsed by a computer, this approach might be more powerful and has the potential of quickly parsing several hundreds of pages looking for the needle in the proverbial haystack.

[0154] In particular embodiments, the search-query layer **205** is capable of building scalable dynamic query containers on the run-time. Using these containers, it is possible to compress a whole set of popular information into one small, typed value. For example, if a request that seeks to know about temperature and humidity in last 5 days becomes popular, then either the search-query layer **205** or indexing layer **204** assigns a standard index to this request. For example, index_n. Next, if a user issues a query with index n for a location X, then the system immediately knows what the parameters the user is trying to search for, and the amount of data needed to convey this query is largely decreased. In particular embodiments, users, engineers and even indexer nodes **26** may propose and design such query containers. Indexer **26** may periodically publish a high level overview of some of the popular queries and engineers/users may use a publicly available API to build and standardize these queries.

[0155] In particular embodiments, the search-query layer **205** may be optimized through the implementation of compound queries. Since indexer nodes **26** form an overlay, the architecture may benefit by using information from various indexer nodes **26** in building a compound query. In a compound query, there may be multiple locations of interest, and the user might be interested in knowing a certain property (or a set of properties) for all of the multiple locations. For example, if a user is traveling from San Jose to Burbank (LA), then he or she may issue a query about temperature, traffic, air-pollution, and rain for the entire route. A set of indexer nodes **26** that have data for various locations in this route may report their own information and, in the end, one of indexer nodes **26** may aggregate this information into one data structure and present it to the user. Thus, the user does not have to type in information for each place separately. As another example, if the user is planning on taking Interstate I-5, then this query may present traffic (current and predicted) for entire route along I-5. Similarly, if a user is interested in organizing an event that has multiple locations, he or she may simply input those locations, and the overlay of indexer nodes **26** will be able to coordinate among themselves to provide the information of interest for all of these locations one page.

[0156] FIG. **8** illustrates an example communication flow for collecting, aggregating, indexing, and querying sensor data. At step **801**, the query is routed from the end-user to the query engine, either through a search engine GUI, or through a program running a search API. At step **802**, the query is routed to indexing layer **204** to determine what indexer node **26** (and, by extension, aggregator node **16** and sensor network) possesses data matching the query specifications. Indexers **26** also sync all their records with its neighboring indexer nodes **26**, which enables the routing algorithm to efficiently deliver the end-user data search request to the appropriate indexer **26**. In particular embodiments, queries are routed over the indexer-based overlay search network, regardless of whether the query is user-generated or is generated by another indexer node **26**. If physical coordinates are specified by the query request, geographical routing is used to search the information within the indexer-based overlay network. Alternatively, when the logical address of the information is known beforehand, then query is routed to the overlay network using IP for routing.

[0157] At step **802**, the query is routed to an indexer node **26** that possesses indexed sensor data that meets the query specifications. In particular embodiments, indexer node **26** has the sensor data specified by the query. In another embodiment, indexer node **26** merely possesses the location of sensor networks that have data meeting the query specification; the actual data generated by sensor network is stored within the sensor network secured central data repository. At step **806**, the metadata information corresponding to the available data is first delivered to search engine **22**. In particular embodiments, the query is formulated such that data from multiple sensor networks may the criteria, and moreover, multiple indexer nodes **26** may be contacted for a single query. Each of indexer nodes **26** transmits metadata to the query generator about its available data.

[0158] In particular embodiments, in-network processing may be performed to quantify the quality of the data. Indexers perform such in-network processing and collaborate with each other to rank data quality available from different sensor networks. When an end-user search request finds the requested data information in an indexer node **26**, the system determines a match. It is possible to have multiple matches, i.e., same data may be available from the multiple sensor networks deployed in the same geographical region. Although the same data is available from multiple sources, the quality of the data may vary. Additionally, at step **806**, the metadata for the matching information is provided back to search engine **22** along with quality of the data metrics. In particular embodiments, indexer node **26** returns the physical or logical name of the sensor network providing the matching data. Indexer node **26** has the responsibility to evaluate the quality of the data when the same data is available from multiple sources/sensor networks. In particular embodiments, indexer nodes **26** may use reliability/timeliness of the data as one parameter to determine quality.

[0159] At step **807**, a ranked list of all the matching data is presented to the end-user. Since sensor data may vary immensely in nature, both in terms of the type of data (temperature, humidity, video, etc) and in terms of the granularity for the data, if a time-scaled query is involved (real-time data, average data, etc). With such a huge variance in sensor data, it is useful to guide the end-user in not only framing the query but also in presentation of the query results. Effective presentation of search results helps in two ways. First, the user does not have to tediously browse pages of less relevant results. Second, with ineffective representation, the result that the user is looking for might be buried in the 20th instead of the first page. A poor experience with result browsing might result in the final product becoming less popular.

[0160] At step **808**, once the end-user is presented with the choices of the search results, the end-user may explicitly decide to retrieve a specific stream of data by selecting the appropriate indexer node **26** and sensor network location that has the desired data. The initial query **801** is sent with Mode set to Search Mode. Once data availability is identified by the query routing infrastructure, the end-user initiates actual data transfer from the source by sending another query with Mode set to Get Mode to the specific source of the data directly (step **808**). At step **809** the sensor data requested by query **808** is delivered to the end-user.

[0161] Systems and methods of implementing an incentive system for sensor nodes **12** (through their gateways **28**) to willingly participate in the system is disclosed herein. The sensor system essentially implements a virtual marketplace where everyone may sell their information. In particular embodiments, an incentive and penalty system is implemented to incentivize participants based on the usability and accuracy of their data, and penalize participants for providing inaccurate information. The system, on the other end, also includes a system to pay for using the search queries. In particular embodiments, a 2 tier model is used. At tier-1, old information from the database or information that is too expensive to be validated by an information broker may be provided free of charge to regular consumers; the cost may be covered through the use of advertisements. At tier-2, highly useful, validated information with high reliability index is sold or auctioned in real-time to Sophisticated Consumers. In another embodiment, this tier could also use subscription model.

[0162] An alternative monetization scheme as envisioned by the disclosure is a business model where Service Providers, such as AT&T, are empowered by a central networking and search provider, such as Cisco, to collect and validate sensor information from participatory sensor nodes **12** (such as cell phones, Call Data Records, Cell Towers, Femto Cells, etc). In particular embodiments, the system provides incentives for the participatory sensor participants (mobile users etc) to share information with Service Providers. The monetization model essentially allows Service Providers to share sensor data collected by its customers globally without providing private information about the participants who provide the information.

[0163] FIG. **9** illustrates an example computer system **900**. In particular embodiments, one or more computer systems **900** perform one or more steps of one or more methods described or illustrated herein. In particular embodiments, one or more computer systems **900** provide functionality described or illustrated herein. In particular embodiments, software running on one or more computer systems **900** performs one or more steps of one or more methods described or illustrated herein or provides functionality described or illustrated herein. Particular embodiments include one or more portions of one or more computer systems **900**.

[0164] This disclosure contemplates any suitable number of computer systems **900**. This disclosure contemplates computer system **900** taking any suitable physical form. As example and not by way of limitation, computer system **900** may be an embedded computer system, a system-on-chip (SOC), a single-board computer system (SBC) (such as, for example, a computer-on-module (COM) or system-on-module (SOM)), a desktop computer system, a laptop or notebook computer system, an interactive kiosk, a mainframe, a mesh of computer systems, a mobile telephone, a personal digital assistant (PDA), a server, a tablet computer system, or a combination of two or more of these. Where appropriate, computer system **900** may include one or more computer systems **900**; be unitary or distributed; span multiple locations; span multiple machines; span multiple datacenters; or reside in a cloud, which may include one or more cloud components in one or more networks. Where appropriate, one or more computer systems **900** may perform without substantial spatial or temporal limitation one or more steps of one or more methods described or illustrated herein. As an example and not by way of limitation, one or more computer systems **900** may perform in real time or in batch mode one or more steps of one or more methods described or illustrated herein. One or more computer systems **900** may perform at different times or at different locations one or more steps of one or more methods described or illustrated herein, where appropriate.

[0165] In particular embodiments, computer system **900** includes a processor **902**, memory **904**, storage **906**, an input/output (I/O) interface **908**, a communication interface **910**, and a bus **912**. Although this disclosure describes and illustrates a particular computer system having a particular number of particular components in a particular arrangement, this disclosure contemplates any suitable computer system having any suitable number of any suitable components in any suitable arrangement.

[0166] In particular embodiments, processor **902** includes hardware for executing instructions, such as those making up a computer program. As an example and not by way of limitation, to execute instructions, processor **902** may retrieve (or fetch) the instructions from an internal register, an internal cache, memory **904**, or storage **906**; decode and execute them; and then write one or more results to an internal register, an internal cache, memory **904**, or storage **906**. In particular embodiments, processor **902** may include one or more internal caches for data, instructions, or addresses. This disclosure contemplates processor **902** including any suitable number of any suitable internal caches, where appropriate. As an example and not by way of limitation, processor **902** may include one or more instruction caches, one or more data caches, and one or more translation lookaside buffers (TLBs). Instructions in the instruction caches may be copies of instructions in memory **904** or storage **906**, and the instruction caches may speed up retrieval of those instructions by processor **902**. Data in the data caches may be copies of data in memory **904** or storage **906** for instructions executing at processor **902** to operate on; the results of previous instructions executed at processor **902** for access by subsequent instructions executing at processor **902** or for writing to memory **904** or storage **906**; or other suitable data. The data caches may speed up read or write operations by processor **902**. The TLBs may speed up virtual-address translation for processor **902**. In particular embodiments, processor **902** may include one or more internal registers for data, instructions, or addresses. This disclosure contemplates processor **902** including any suitable number of any suitable internal registers, where appropriate. Where appropriate, processor **902** may include one or more arithmetic logic units (ALUs); be a multi-core processor; or include one or more processors **902**. Although this disclosure describes and illustrates a particular processor, this disclosure contemplates any suitable processor.

[0167] In particular embodiments, memory **904** includes main memory for storing instructions for processor **902** to execute or data for processor **902** to operate on. As an example and not by way of limitation, computer system **900** may load instructions from storage **906** or another source (such as, for example, another computer system **900**) to memory **904**. Processor **902** may then load the instructions from memory **904** to an internal register or internal cache. To execute the instructions, processor **902** may retrieve the instructions from the internal register or internal cache and decode them. During or after execution of the instructions, processor **902** may write one or more results (which may be intermediate or final results) to the internal register or internal cache. Processor **902** may then write one or more of those results to memory **904**. In particular embodiments, processor **902** executes only instructions in one or more internal registers or internal caches or in memory **904** (as opposed to storage **906** or elsewhere) and operates only on data in one or more internal registers or internal caches or in memory **904** (as opposed to storage **906** or elsewhere). One or more memory buses (which may each include an address bus and a data bus) may couple processor **902** to memory **904**. Bus **912** may include one or more memory buses, as described below. In particular embodiments, one or more memory management units (MMUs) reside between processor **902** and memory **904** and facilitate accesses to memory **904** requested by processor **902**. In particular embodiments, memory **904** includes random access memory (RAM). This RAM may be volatile memory, where appropriate Where appropriate, this RAM may be dynamic RAM (DRAM) or static RAM (SRAM). Moreover, where appropriate, this RAM may be single-ported or multi-ported RAM. This disclosure contemplates any suitable RAM. Memory **904** may include one or more memories **904**, where appropriate. Although this disclosure describes and illustrates particular memory, this disclosure contemplates any suitable memory.

[0168] In particular embodiments, storage **906** includes mass storage for data or instructions. As an example and not by way of limitation, storage **906** may include an HDD, a floppy disk drive, flash memory, an optical disc, a magneto-optical disc, magnetic tape, or a Universal Serial Bus (USB) drive or a combination of two or more of these. Storage **906** may include removable or non-removable (or fixed) media, where appropriate. Storage **906** may be internal or external to computer system **900**, where appropriate. In particular embodiments, storage **906** is non-volatile, solid-state memory. In particular embodiments, storage **906** includes read-only memory (ROM). Where appropriate, this ROM may be mask-programmed ROM, programmable ROM (PROM), erasable PROM (EPROM), electrically erasable PROM (EEPROM), electrically alterable ROM (EAROM), or flash memory or a combination of two or more of these. This disclosure contemplates mass storage **906** taking any suitable physical form. Storage **906** may include one or more storage control units facilitating communication between processor **902** and storage **906**, where appropriate. Where appropriate, storage **906** may include one or more storages **909**. Although this disclosure describes and illustrates particular storage, this disclosure contemplates any suitable storage.

[0169] In particular embodiments, I/O interface **908** includes hardware, software, or both providing one or more interfaces for communication between computer system **900** and one or more I/O devices. Computer system **900** may include one or more of these I/O devices, where appropriate. One or more of these I/O devices may enable communication between a person and computer system **900**. As an example and not by way of limitation, an I/O device may include a keyboard, keypad, microphone, monitor, mouse, printer, scanner, speaker, still camera, stylus, tablet, touch screen, trackball, video camera, another suitable I/O device or a combination of two or more of these. An I/O device may include one or more sensor nodes **12**. This disclosure contemplates any suitable I/O devices and any suitable I/O interfaces **908** for them. Where appropriate, I/O interface **908** may include one or more device or software drivers enabling processor **902** to drive one or more of these I/O devices. I/O interface **908** may include one or more I/O interfaces **908**, where appropriate. Although this disclosure describes and illustrates a particular I/O interface, this disclosure contemplates any suitable I/O interface.

[0170] In particular embodiments, communication interface **910** includes hardware, software, or both providing one or more interfaces for communication (such as, for example, packet-based communication) between computer system **900** and one or more other computer systems **900** or one or more networks. As an example and not by way of limitation, communication interface **910** may include a network interface controller (NIC) or network adapter for communicating with an Ethernet or other wire-based network or a wireless NIC (WNIC) or wireless adapter for communicating with a wireless network, such as a WI-FI network. This disclosure contemplates any suitable network and any suitable communication interface **910** for it. As an example and not by way of limitation, computer system **900** may communicate with an ad hoc network, a personal area network (PAN), a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), or one or more portions of the Internet or a combination of two or more of these. One or more portions of one or more of these networks may be wired or wireless. As an example, computer system **900** may communicate with a wireless PAN (WPAN) (such as, for example, a BLUETOOTH WPAN), a WI-FI network, a WI-MAX network, a cellular telephone network (such as, for example, a Global System for Mobile Communications (GSM) network), or other suitable wireless network or a combination of two or more of these. Computer system **900** may include any suitable communication interface **910** for any of these networks, where appropriate. Communication interface **910** may include one or more communication interfaces **910**, where appropriate. Although this disclosure describes and illustrates a particular communication interface, this disclosure contemplates any suitable communication interface.

[0171] In particular embodiments, bus **912** includes hardware, software, or both coupling components of computer system **900** to each other. As an example and not by way of limitation, bus **912** may include an Accelerated Graphics Port (AGP) or other graphics bus, an Enhanced Industry Standard Architecture (EISA) bus, a front-side bus (FSB), a HYPERTRANSPORT (HT) interconnect, an Industry Standard Architecture (ISA) bus, an INFINIBAND interconnect, a low-pin-count (LPC) bus, a memory bus, a Micro Channel Architecture (MCA) bus, a Peripheral Component Interconnect (PCI) bus, a PCI-Express (PCI-X) bus, a serial advanced technology attachment (SATA) bus, a Video Electronics Standards Association local (VLB) bus, or another suitable bus or a combination of two or more of these. Bus **912** may include one or more buses **912**, where appropriate. Although this disclosure describes and illustrates a particular bus, this disclosure contemplates any suitable bus or interconnect.

[0172] Herein, reference to a computer-readable storage medium encompasses one or more non-transitory, tangible computer-readable storage media possessing structure. As an example and not by way of limitation, a computer-readable storage medium may include a semiconductor-based or other integrated circuit (IC) (such, as for example, a field-programmable gate array (FPGA) or an application-specific IC (ASIC)), a hard disk, an HDD, a hybrid hard drive (HHD), an optical disc, an optical disc drive (ODD), a magneto-optical disc, a magneto-optical drive, a floppy disk, a floppy disk drive (FDD), magnetic tape, a holographic storage medium, a solid-state drive (SSD), a RAM-drive, a SECURE DIGITAL card, a SECURE DIGITAL drive, or another suitable computer-readable storage medium or a combination of two or more of these, where appropriate. Herein, reference to a computer-readable storage medium excludes any medium that is not eligible for patent protection under 35 U.S.C. §101. Herein, reference to a computer-readable storage medium excludes transitory forms of signal transmission (such as a propagating electrical or electromagnetic signal per se) to the extent that they are not eligible for patent protection under 35 U.S.C. §101. A computer-readable non-transitory storage medium may be volatile, non-volatile, or a combination of volatile and non-volatile, where appropriate.

[0173] This disclosure contemplates one or more computer-readable storage media implementing any suitable storage. In particular embodiments, a computer-readable storage medium implements one or more portions of processor **902** (such as, for example, one or more internal registers or caches), one or more portions of memory **904**, one or more portions of storage **906**, or a combination of these, where appropriate. In particular embodiments, a computer-readable storage medium implements RAM or ROM. In particular embodiments, a computer-readable storage medium implements volatile or persistent memory. In particular embodiments, one or more computer-readable storage media embody software. Herein, reference to software may encompass one or more applications, bytecode, one or more computer programs, one or more executables, one or more instructions, logic, machine code, one or more scripts, or source code, and vice versa, where appropriate. In particular embodiments, software includes one or more application programming interfaces (APIs). This disclosure contemplates any suitable software written or otherwise expressed in any suitable programming language or combination of programming languages. In particular embodiments, software is expressed as source code or object code. In particular embodiments, software is expressed in a higher-level programming language, such as, for example, C, Perl, or a suitable extension thereof. In particular embodiments, software is expressed in a lower-level programming language, such as assembly language (or machine code). In particular embodiments, software is expressed in JAVA. In particular embodiments, software is expressed in Hyper Text Markup Language (HTML), Extensible Markup Language (XML), or other suitable markup language.

[0174] FIG. **10** illustrates an example network environment **1000**. This disclosure contemplates any suitable network environment **1000**. As an example and not by way of limitation, although this disclosure describes and illustrates a network environment **1000** that implements a client-server model, this disclosure contemplates one or more portions of a network environment **1000** being peer-to-peer, where appropriate. Particular embodiments may operate in whole or in part in one or more network environments **1000**. In particular embodiments, one or more elements of network environment **1000** provide functionality described or illustrated herein. Particular embodiments include one or more portions of network environment **1000**. Network environment **1000** includes a network **1010** coupling one or more servers **1020** and one or more clients **1030** to each other. This disclosure contemplates any suitable network **1010**. As an example and not by way of limitation, one or more portions of network **1010** may include an ad hoc network, an intranet, an extranet, a virtual private network (VPN), a local area network (LAN), a wireless LAN (WLAN), a wide area network (WAN), a wireless WAN (WWAN), a metropolitan area network (MAN), a portion of the Internet, a portion of the Public Switched Telephone Network (PSTN), a cellular telephone network, or a combination of two or more of these. Network **1010** may include one or more networks **1010**.

[0175] Links **1050** couple servers **1020** and clients **1030** to network **1010** or to each other. This disclosure contemplates any suitable links **1050**. As an example and not by way of limitation, one or more links **1050** each include one or more wireline (such as, for example, Digital Subscriber Line (DSL) or Data Over Cable Service Interface Specification (DOCSIS)), wireless (such as, for example, Wi-Fi or Worldwide Interoperability for Microwave Access (WiMAX)) or optical (such as, for example, Synchronous Optical Network (SONET) or Synchronous Digital Hierarchy (SDH)) links **1050**. In particular embodiments, one or more links **1050** each includes an intranet, an extranet, a VPN, a LAN, a WLAN, a WAN, a MAN, a communications network, a satellite network, a portion of the Internet, or another link **1050** or a combination of two or more such links **1050**. Links **1050** need not necessarily be the same throughout network environment **1000**. One or more first links **1050** may differ in one or more respects from one or more second links **1050**.

[0176] This disclosure contemplates any suitable servers **1020**. As an example and not by way of limitation, one or more servers **1020** may each include one or more advertising servers, applications servers, catalog servers, communications servers, database servers, exchange servers, fax servers, file servers, game servers, home servers, mail servers, message servers, news servers, name or DNS servers, print servers, proxy servers, sound servers, standalone servers, web servers, or web-feed servers. In particular embodiments, a server **1020** includes hardware, software, or both for providing the functionality of server **1020**. As an example and not by way of limitation, a server **1020** that operates as a web server may be capable of hosting websites containing web pages or elements of web pages and include appropriate hardware, software, or both for doing so. In particular embodiments, a web server may host HTML or other suitable files or dynamically create or constitute files for web pages on request. In response to a Hyper Text Transfer Protocol (HTTP) or other request from a client **1030**, the web server may communicate one or more such files to client **1030**. As another example, a server **1020** that operates as a mail server may be capable of providing e-mail services to one or more clients **1030**. As another example, a server **1020** that operates as a database server may be capable of providing an interface for interacting with one or more data stores (such as, for example, data stores **10100** described below). Where appropriate, a server **1020** may include one or more servers **1020**; be unitary or distributed; span multiple locations; span multiple machines; span multiple datacenters; or reside in a cloud, which may include one or more cloud components in one or more networks.

[0177] In particular embodiments, one or more links **1050** may couple a server **1020** to one or more data stores **1040**. A data store **1040** may store any suitable information, and the contents of a data store **1040** may be organized in any suitable manner. As an example and not by way or limitation, the contents of a data store **1040** may be stored as a dimensional, flat, hierarchical, network, object-oriented, relational, XML, or other suitable database or a combination or two or more of these. A data store **1040** (or a server **1020** coupled to it) may include a database-management system or other hardware or software for managing the contents of data store **1040**. The database-management system may perform read and write operations, delete or erase data, perform data deduplication, query or search the contents of data store **1040**, or provide other access to data store **1040**.

[0178] In particular embodiments, one or more servers **1020** may each include one or more search engines **1022**. A search engine **1022** may include hardware, software, or both for providing the functionality of search engine **1022**. As an example and not by way of limitation, a search engine **1022** may implement one or more search algorithms to identify network resources in response to search queries received at search engine **1022**, one or more ranking algorithms to rank identified network resources, or one or more summarization algorithms to summarize identified network resources. In particular embodiments, a ranking algorithm implemented by a search engine **1022** may use a machine-learned ranking formula, which the ranking algorithm may obtain automatically from a set of training data constructed from pairs of search queries and selected Uniform Resource Locators (URLs), where appropriate.

[0179] In particular embodiments, one or more servers **1020** may each include one or more data monitors/collectors **1024**. A data monitor/collection **1024** may include hardware, software, or both for providing the functionality of data collector/collector **1024**. As an example and not by way of limitation, a data monitor/collector **1024** at a server **1020** may monitor and collect network-traffic data at server **1020** and store the network-traffic data in one or more data stores **1040**. In particular embodiments, server **1020** or another device may extract pairs of search queries and selected URLs from the network-traffic data, where appropriate.

[0180] This disclosure contemplates any suitable clients **1030**. A client **1030** may enable a user at client **1030** to access or otherwise communicate with network **1010**, servers **1020**, or other clients **1030**. As an example and not by way of limitation, a client **1030** may have a web browser, such as MICROSOFT INTERNET EXPLORER or MOZILLA FIREFOX, and may have one or more add-ons, plug-ins, or other extensions, such as GOOGLE TOOLBAR or YAHOO TOOLBAR. A client **1030** may be an electronic device including hardware, software, or both for providing the functionality of client **1030**. As an example and not by way of limitation, a client **1030** may, where appropriate, be an embedded computer system, an SOC, an SBC (such as, for example, a COM or SOM), a desktop computer system, a laptop or notebook computer system, an interactive kiosk, a mainframe, a mesh of computer systems, a mobile telephone, a PDA, a netbook computer system, a server, a tablet computer system, or a combination of two or more of these. Where appropriate, a client **1030** may include one or more clients **1030**; be unitary or distributed; span multiple locations; span multiple machines; span multiple datacenters; or reside in a cloud, which may include one or more cloud components in one or more networks.

[0181] Herein, "or" is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A or B" means "A, B, or both," unless expressly indicated otherwise or indicated otherwise by context. Moreover, "and" is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A and B" means "A and B, jointly or severally," unless expressly indicated otherwise or indicated otherwise by context.

[0182] This disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Similarly, where appropriate, the appended claims encompass all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Moreover, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative.

What is claimed is:

1. A method comprising, by one or more computer systems:

receiving a query for particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes;

translating the query to correspond to the indexing of the plurality of sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array; and

communicating the translated query to search among the plurality of sensor data according to its indexing to identify the particular sensor data.

2. The method of claim **1**, wherein communicating the translated query comprises transmitting the query to a search engine that responds with a set of sensor data with substantially similar values for the one or more dimensions as the multidimensional array in the translated query.

3. The method of claim **1**, wherein the query is generated by a user.

4. The method of claim **1**, wherein the query is generated by a sensor network through the use of an a standard application program interface.

5. The method of claim **3**, wherein translating the query comprises:

searching a cache of a set of recent popular queries for a cached query that is substantially similar to the query received from the user,

suggesting one or more of the cached queries to the user; and

in response to a user input selecting one of the suggested cached queries, translating the received query into the selected query.

6. The method of claim **1**, further comprising:

receiving query results comprising meta data associated with a subset of the plurality of sensors;

selecting a particular one of the subset of sensors; and

requesting the data available at the particular one of the subset of sensors.

7. The method of claim **1**, further comprising appending an option unique resource locator to the query, the option unique resource locator specifying a specific sensor; and

communicating the query directly to the specific sensor.

8. The method of claim **1**, wherein one of the dimensions of the multi-dimensional array comprises one or more values specifying data type.

9. The method of claim **8**, wherein the value is numerical

10. The method of claim **8**, wherein the value is text.

11. A method comprising, by one or more computer systems:

receiving a translated query for particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes, the translated query having been translated from an original query for the particular sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array;

generating one or more multi-dimensional-array filters based on the translated query; and

applying one or more of the multi-dimensional-array filters to the plurality of sensor data as indexed to identify the particular sensor data among a plurality of sensor data for a response to the original query.

12. The method of claim **11**, wherein one or more of the multi-dimensional-array filters omits any sensor data below a ranking specified by the translated query.

13. The method of claim **11**, wherein one of the multi-dimensional-array filters omits any sensor data not falling within a time range specified by the translated query.

14. The method of claim **11**, wherein one of the multi-dimensional-array filters omits any sensor data not falling within a distance specified by the translated query to a location specified by the translated query.

15. The method of claim **11**, further comprising modifying the query before filtering based on stored preferences of the query originator.

16. The method of claim **11**, further comprising:

accessing a cache of popular queries and their associated results;

determining whether the received translated query matches one of the queries in the cache of popular queries; and

in response to a determination that the received translated query matches one of the queries in the cache of popular queries, communicating the results associated with the matched query in the cache of popular queries to the query originator.

17. A method comprising, by one or more computer systems:

receiving information identifying particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes, the translated query having been translated from an original query for the particular sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array, the particular sensor data having been identified by applying one or more multi-dimensional-array filters to the plurality of sensor data as indexed, one or more of the multi-dimensional-array filters having been generated based on a translated query translated from an original query for the particular sensor data, the translated query having comprised one or more values for one or more of the dimensions of the multi-dimensional array;

sorting the information based on a stored profile of a user; and

communicating the information as sorted for display to the user, the display of the information providing a response to the original query.

18. The method of claim **17**, wherein sorting the list comprises ordering the information such that the information that is the most relevant to the user is displayed first.

19. The method of claim **18**, wherein the relevance of the information is determined at least in part by the popularity of sensor communicating the information.

20. The method of claim **18**, wherein the stored profile of a user comprises its location, and the relevance of the information is determined at least in part by the user's location.

21. The method of claim **18**, wherein communicating the sorted information for display comprises:

rendering a page comprising multiple panels on the user's display;

determining, for each sensor data in the sorted information, which panel the sensor data is most relevant to; and

rendering each sensor data in its most relevant panel.

22. The method of claim **21**, wherein rendering each sensor data in its most relevant panel comprises:

generating a link for each sensor data operable to, when selected, retrieve requested sensor data; and

pre-caching each of the links by setting up the session for the link.

23. The method of claim **18**, wherein the relevance of each sensor data is determined at least in part by its number of data dimensions.

24. The method of claim **18**, wherein the relevance of each sensor data is determined at least in part by the reputation of the sensor data originator.

25. One or more computer-readable non-transitory storage media embodying software that is operable when executed to:

receive a query for particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes;

translate the query to correspond to the indexing of the plurality of sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array; and

communicate the translated query to search among the plurality of sensor data according to its indexing to identify the particular sensor data.

26. The media of claim **25**, wherein communicating the translated query comprises transmitting the query to a search engine that responds with a set of sensor data with substantially similar values for the one or more dimensions as the multidimensional array in the translated query.

27. The media of claim **25**, wherein the query is generated by a user.

28. The media of claim **25**, wherein the query is generated by a sensor network through the use of an a standard application program interface.

29. The media of claim **27**, wherein translating the query comprises:

searching a cache of a set of recent popular queries for a cached query that is substantially similar to the query received from the user,

suggesting one or more of the cached queries to the user; and

in response to a user input selecting one of the suggested cached queries, translating the received query into the selected query.

30. The media of claim **25**, further comprising software that is operable when executed to:

receive query results comprising meta data associated with a subset of the plurality of sensors;

select a particular one of the subset of sensors; and
request the data available at the particular one of the subset of sensors.

31. The media of claim **25**, further comprising software that is operable when executed to:
append an option unique resource locator to the query, the option unique resource locator specifying a specific sensor; and
communicate the query directly to the specific sensor.

32. The media of claim **25**, wherein one of the dimensions of the multi-dimensional array comprises one or more values specifying data type.

33. The media of claim **32**, wherein the value is numerical

34. The media of claim **32**, wherein the value is text.

35. One or more computer-readable non-transitory storage media embodying software that is operable when executed to:
receive a translated query for particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes, the translated query having been translated from an original query for the particular sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array;
generate one or more multi-dimensional-array filters based on the translated query; and
apply one or more of the multi-dimensional-array filters to the plurality of sensor data as indexed to identify the particular sensor data among a plurality of sensor data for a response to the original query.

36. The media of claim **35**, wherein one or more of the multi-dimensional-array filters omits any sensor data below a ranking specified by the translated query.

37. The media of claim **35**, wherein one of the multi-dimensional-array filters omits any sensor data not falling within a time range specified by the translated query.

38. The media of claim **35**, wherein one of the multi-dimensional-array filters omits any sensor data not falling within a distance specified by the translated query to a location specified by the translated query.

39. The media of claim **35**, further comprising software operable when executed to modify the query before filtering based on stored preferences of the query originator.

40. The media of claim **35**, further comprising software operable when executed to:
access a cache of popular queries and their associated results;
determine whether the received translated query matches one of the queries in the cache of popular queries; and
in response to a determination that the received translated query matches one of the queries in the cache of popular queries, communicating the results associated with the matched query in the cache of popular queries to the query originator.

41. One or more computer-readable non-transitory storage media embodying software that is operable when executed to:
receive information identifying particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes, the translated query having been translated from an original query for the particular sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array, the particular sensor data having been identified by applying one or more multi-dimensional-array filters to the plurality of sensor data as indexed, one or more of the multi-dimensional-array filters having been generated based on a translated query translated from an original query for the particular sensor data, the translated query having comprised one or more values for one or more of the dimensions of the multi-dimensional array;
sort the information based on a stored profile of a user; and
communicate the information as sorted for display to the user, the display of the information providing a response to the original query.

42. The media of claim **41**, wherein sorting the list comprises ordering the information such that the information that is the most relevant to the user is displayed first.

43. The media of claim **42**, wherein the relevance of the information is determined at least in part by the popularity of sensor communicating the information.

44. The media of claim **42**, wherein the stored profile of a user comprises its location, and the relevance of the information is determined at least in part by the user's location.

45. The media of claim **42**, wherein communicating the sorted information for display comprises:
rendering a page comprising multiple panels on the user's display;
determining, for each sensor data in the sorted information, which panel the sensor data is most relevant to; and
rendering each sensor data in its most relevant panel.

46. The media of claim **45**, wherein rendering each sensor data in its most relevant panel comprises:
generating a link for each sensor data operable to, when selected, retrieve requested sensor data; and
pre-caching each of the links by setting up the session for the link.

47. The media of claim **42**, wherein the relevance of each sensor data is determined at least in part by its number of data dimensions.

48. The media of claim **42**, wherein the relevance of each sensor data is determined at least in part by the reputation of the sensor data originator.

49. A apparatus comprising:
one or more communication interfaces;
one or more memory devices containing one or more instructions for execution by one or more processing devices; and
the processing devices operable when executing the instructions to:
receive a query for particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes;
translate the query to correspond to the indexing of the plurality of sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array; and

communicate the translated query to search among the plurality of sensor data according to its indexing to identify the particular sensor data.

50. The apparatus of claim **49**, wherein communicating the translated query comprises transmitting the query to a search engine that responds with a set of sensor data with substantially similar values for the one or more dimensions as the multidimensional array in the translated query.

51. The apparatus of claim **49**, wherein the query is generated by a user.

52. The apparatus of claim **49**, wherein the query is generated by a sensor network through the use of an a standard application program interface.

53. The apparatus of claim **51**, wherein translating the query comprises:

searching a cache of a set of recent popular queries for a cached query that is substantially similar to the query received from the user,

suggesting one or more of the cached queries to the user; and

in response to a user input selecting one of the suggested cached queries, translating the received query into the selected query.

54. The apparatus of claim **49**, the processing devices further operable when executing the instructions to:

receive query results comprising meta data associated with a subset of the plurality of sensors;

select a particular one of the subset of sensors; and

request the data available at the particular one of the subset of sensors.

55. The apparatus of claim **49**, the processing devices further operable when executing the instructions to:

append an option unique resource locator to the query, the option unique resource locator specifying a specific sensor; and

communicate the query directly to the specific sensor.

56. The apparatus of claim **49**, wherein one of the dimensions of the multi-dimensional array comprises one or more values specifying data type.

57. The apparatus of claim **56**, wherein the value is numerical.

58. The apparatus of claim **56**, wherein the value is text.

59. A apparatus comprising:

one or more communication interfaces;

one or more memory devices containing one or more instructions for execution by one or more processing devices; and

the processing devices operable when executing the instructions to:

receive a translated query for particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes, the translated query having been translated from an original query for the particular sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array;

generate one or more multi-dimensional-array filters based on the translated query; and

apply one or more of the multi-dimensional-array filters to the plurality of sensor data as indexed to identify the particular sensor data among a plurality of sensor data for a response to the original query.

60. The apparatus of claim **59**, wherein one or more of the multi-dimensional-array filters omits any sensor data below a ranking specified by the translated query.

61. The apparatus of claim **59**, wherein one of the multi-dimensional-array filters omits any sensor data not falling within a time range specified by the translated query.

62. The apparatus of claim **59**, wherein one of the multi-dimensional-array filters omits any sensor data not falling within a distance specified by the translated query to a location specified by the translated query.

63. The apparatus of claim **59**, the processing devices further operable when executing the instructions to:

modify the query before filtering based on stored preferences of the query originator.

64. The apparatus of claim **59**, the processing devices further operable when executing the instructions to:

access a cache of popular queries and their associated results;

determine whether the received translated query matches one of the queries in the cache of popular queries; and

in response to a determination that the received translated query matches one of the queries in the cache of popular queries, communicating the results associated with the matched query in the cache of popular queries to the query originator.

65. A apparatus comprising:

one or more communication interfaces;

one or more memory devices containing one or more instructions for execution by one or more processing devices; and

the processing devices operable when executing the instructions to

receive information identifying particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes, the translated query having been translated from an original query for the particular sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array, the particular sensor data having been identified by applying one or more multi-dimensional-array filters to the plurality of sensor data as indexed, one or more of the multi-dimensional-array filters having been generated based on a translated query translated from an original query for the particular sensor data, the translated query having comprised one or more values for one or more of the dimensions of the multi-dimensional array;

sort the information based on a stored profile of a user; and

communicate the information as sorted for display to the user, the display of the information providing a response to the original query.

66. The apparatus of claim **65**, wherein sorting the list comprises ordering the information such that the information that is the most relevant to the user is displayed first.

67. The apparatus of claim **66**, wherein the relevance of the information is determined at least in part by the popularity of sensor communicating the information.

68. The apparatus of claim **66**, wherein the stored profile of a user comprises its location, and the relevance of the information is determined at least in part by the user's location.

69. The apparatus of claim **65**, wherein communicating the sorted information for display comprises:

rendering a page comprising multiple panels on the user's display;

determining, for each sensor data in the sorted information, which panel the sensor data is most relevant to; and

rendering each sensor data in its most relevant panel.

70. The apparatus of claim **69**, wherein rendering each sensor data in its most relevant panel comprises:

generating a link for each sensor data operable to, when selected, retrieve requested sensor data; and

pre-caching each of the links by setting up the session for the link.

71. The apparatus of claim **66**, wherein the relevance of each sensor data is determined at least in part by its number of data dimensions.

72. The apparatus of claim **66**, wherein the relevance of each sensor data is determined at least in part by the reputation of the sensor data originator.

73. A system comprising:

means for receiving a query for particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes;

means for translating the query to correspond to the indexing of the plurality of sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array; and

means for communicating the translated query to search among the plurality of sensor data according to its indexing to identify the particular sensor data.

74. A system comprising:

means for receiving a translated query for particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes, the translated query having been translated from an original query for the particular sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array;

means for generating one or more multi-dimensional-array filters based on the translated query; and

means for applying one or more of the multi-dimensional-array filters to the plurality of sensor data as indexed to identify the particular sensor data among a plurality of sensor data for a response to the original query.

75. A system comprising:

means for receiving information identifying particular sensor data among a plurality of sensor data from a plurality of sensors, the plurality of sensor data being indexed according to a multi-dimensional array, one or more first ones of the dimensions comprising time and one or more second ones of the dimensions comprising one or more pre-determined sensor-data attributes, the translated query having been translated from an original query for the particular sensor data, the translated query comprising one or more values for one or more of the dimensions of the multi-dimensional array, the particular sensor data having been identified by applying one or more multi-dimensional-array filters to the plurality of sensor data as indexed, one or more of the multi-dimensional-array filters having been generated based on a translated query translated from an original query for the particular sensor data, the translated query having comprised one or more values for one or more of the dimensions of the multi-dimensional array;

means for sorting the information based on a stored profile of a user; and

means for communicating the information as sorted for display to the user, the display of the information providing a response to the original query.

* * * * *