A Service-Centric Model for Wireless Sensor Networks

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***Abstract*—Most of the current research in wireless sensor networks (WSNs) is constraint driven and focuses on optimizing the use of limited resources (e.g., power) at each sensor. While such constraints are important, there is a energy for more general performance metrics to assess the effectiveness of WSNs. There is also a need for a unified formal model that would enable comparison of different types of WSNs and provide a framework for WSN operations. We propose a new service-centric model that focuses on services provided by a WSN and views a WSN as a service provider. A WSN is modeled at different levels of abstraction. For each level, a set of services and a set of metrics are defined. Services and their interfaces are defined in a formal way to facilitate automatic composition of services, and enable interoperability and multitasking of WSNs at the different levels. A two-way mapping between two neighboring levels is then defined as a decomposition (from higher to lower level) and composition (from lower to higher level). A composite mapping between metrics at different levels connects high-level, mission-oriented metrics and low-level, capability-oriented metrics. The service-centric model consists of mission, network, region, sensor, and capability layers. Each layer has associated semantics that use lower level components as syntactic units (except for the capability layer). Within each layer there are four planes or functionality sets; communication, management, application, and generational learning. The combination of layers and planes enables a service-based visualization paradigm that can provide better understanding of the WSN. The service-centric model provides a holistic approach to measuring and presenting WSNs effectiveness. In addition, it presents a general and flexible framework in which various more specific WSN models can be represented and evaluated.**

***Index Terms*—Generational learning, sensor network modeling, service definition, service management, visualization.**

I. INTRODUCTION

A WIRELESS SENSOR NETWORK (WSN) consists of a large number of sensor nodes (sensors for short) that act cooperatively to collect raw data and to provide "*usable chunks of predigested information rather than a confusing wash of numbers*" [1]. That amounts to providing a service or a collection of services based on sensor capabilities and the underlying communication infrastructure.

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Distinguishing characteristics of WSNs include a large number of nodes, each of which has limited processing and transmission capabilities and a finite lifetime, due to nonreplenishable energy sources. As WSNs evolve, models and techniques are needed to analyze, verify, predict the behavior of, and effectively operate a WSN. The model must accurately describe the WSN's architecture, capabilities, and functionality to provide for proper depiction of the WSN's behavior. Ideally, the model should be applicable to a wide range of WSNs to provide for comparison. WSN models discussed in the literature include resource-centric, network-centric, and data-centric models [2]. They express, in different ways and to varying degrees, the WSNs desired functionality, as well as its architecture, communications infrastructure, mobility, scale, and control.

Most existing WSNs adopt resource-centric models. These models are constraint driven, focusing on optimizing the use of limited resources (primarily energy) at individual sensors. The aim is to increase longevity of individual sensors through load balancing, sleep cycles, and minimization of control traffic. While node longevity is an important metric, there may be times when it is crucial that particular sensors be active and sending data, even at the expense of a reduced lifetime, to accomplish the goals of the network as a whole. Such network-wide goals are not captured in a resource-centric model.

An alternative model is the network-centric model, which has limited awareness of the semantics of both the application and the network traffic. The high degree of correlation in data gathered by neighboring sensors leads to redundant information being propagated across a WSN. It follows that, only using node addresses to propagate the data without examining the data content of packets, which is the case in the basic network-centric model, may lead to ineffective use of the network.

Yet another popular model, the data-centric model, relies heavily on data identifiers and prespecified locations, limiting its scalability and application to randomly-deployed WSNs. The emphasis on (refined) data leads to a view of a WSN as a distributed database (a data-centric view). An example is TinyDB [3], a query processing system for extracting information from a network of TinyOS sensors [4]. TinyDB provides a simple query language to specify required data. Given the query, TinyDB collects that data from sensor nodes, filters it, aggregates it together, and routes it out. The focus on data location, acquisition, and propagation is mainly motivated by resource constraints, i.e., how to reduce power consumption. One can argue that the resource-centric model is subsumed in the data-centric model.

WSNs are mission-oriented. Sensors collectively deliver services to accomplish the network's mission based on their sensing, computing, storage, communication, and energy capabilities, and on the data they collect and process. We view a WSN as a mission-driven service provider. The objective is to deliver services efficiently subject to the quality-of-service (QoS) requested by service requesters and the physical constraints of the network.

In this paper, we propose a service-centric view, where a mission oriented performance evaluation may take precedence over resource-based performance measures. Security issues and service availability are other important aspects [5]. The distributed nature of WSNs and the corresponding service-centric view have many similarities to web services. Indeed, WSNs and web services are on markedly different sides of the network applications spectrum, but it is feasible to provide WSN services within the framework of web services.

Our goal is to provide a general service-centric WSN model that includes data-centric, network-centric, and resource-centric views as special cases. Such a unified model allows for comparison of different types of WSNs. It provides a flexible and comprehensive framework for expressing and evaluating capabilities, functionalities, management, behavior, and evolution of a WSN. Just as importantly, a service-centric model may lead to design decisions regarding the structure of the network and the protocols for data collection, aggregation, and forwarding that might be expected from the data, network, and resource-centric models.

The remainder of the paper is organized as follows. Section II describes the service-centric WSN model. Section III provides some formalisms for the service-centric model and describes a visualization paradigm enabled by the service-centric model. Section IV provides a case study, while Section V concludes the paper.

II. Modeling Wireless Sensor Networks

WSN components to include architecture, protocols, management system, applications, and interfaces are needed for WSNs to deliver their service results. A "service" is a unit of operation upon which the various WSN components are defined. A service can be informally defined as a typed abstraction that encapsulates "an organizational unit," for example, data, or a set of operations with associated logic, and that has a programmable interface. A service can be defined, discovered, instantiated (subject to QoS constraints), invoked, and can be composed through service input/output connectors. The type of a service depends on the encapsulated organizational unit, and the functionality exposed by the interface, for example retrieval, storage, manipulation, communication, configuration, control, or a hybrid. In this section, we describe a WSN and informally define a five-layer service-centric WSN model. In Section II-A, we provide a more formal definition of our model.

A. *Wireless Sensor Network (WSN)*

Individual sensors are tiny mass-produced, commodity devices, lacking unique identifiers. Sensors have a nonrenewable power supply. Sensors can be deployed randomly and, once deployed, they self organize into a network that works autonomously. Sensors are in sleep mode most of the time, switching to active mode under the control of an internal timer. Due to its modest transmission range, messages sent by a sensor can reach only the sensors in its immediate proximity, a tiny fraction of the overall sensor population. The WSN is connected to the outside world through a sink, whose role is also to collect the information generated by the network. The sink has a full range of computational capabilities, is capable of sending long-range directional broadcasts to all sensors and has a steady power supply. Overlaying a virtual infrastructure on the sensor nodes, the network is divided into addressable regions. Each region contains a set of sensor nodes. An example of such an organization can be provided using a base station, or a sink, that serves as a center of the polar coordinate system. The distance between a sensor and the sink is determined based on the (quantified) base-station signal level, as measured by a sensor node. The (quantified) angle between a sensor and the sink (relative to a reference direction) is determined by focused transmission from the sink. As a result, the area covered with sensors is divided into regions. Each region is uniquely identified by its distance from the sink and its angle. All sensors within the region share the same region identifier [6]. Our model is developed based on the following assumptions [7].

- The sensors may be anonymous, i.e., they may lack unique identifiers (e.g., addresses).
- Several sensors can create a region (group): anonymity of a sensor in a WSN dictates the creation of regions.
- Each sensor belongs to exactly one region: the identity of this region is the only identifier initially available to the sensor.
- A region has an address (e.g., coordinates) that uniquely identifies the region; no two regions can have the same address.
- Communication among regions is based on addresses.
- Sensor synchronization is short-lived and group-based, where a group is loosely defined as the collection of sensors that collaborate to provide a given service.

B. *Service-Centric Wireless Sensor Network Model*

If each sensor had a unique identifier, then some available layered models like OSI or DARPA [8] could have been adapted to model the WSN. However, uniqueness of addresses may not be feasible or even required. It is also worth noting that the bottom-up view of a WSN that focuses on optimizing the performance of individual sensor nodes, typically based on energy consumption, may not yield optimum results when considering the mission of the whole network. For example, when a critical event (say, fire) is detected, it may be important that a sensor respond immediately even if this will deplete its remaining energy. On the other hand, a top–down view that focuses on optimization of individual service requests also may not yield optimum results when considering the mission of the entire network. We surmise that a service-centric model that focuses on the mission of the network will result in more effective component definitions and, consequently,

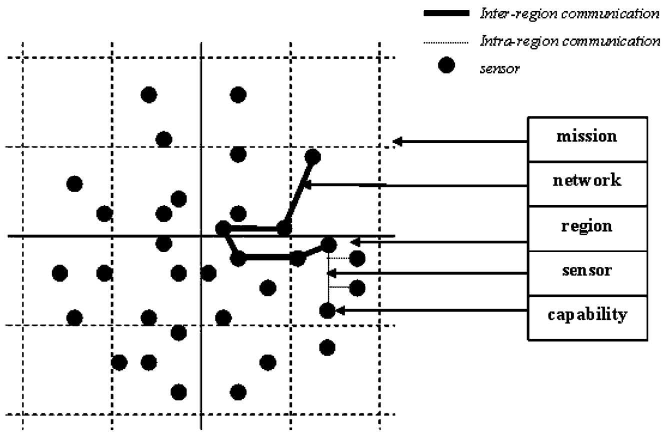

Fig. 1. Generic WSN deployment.

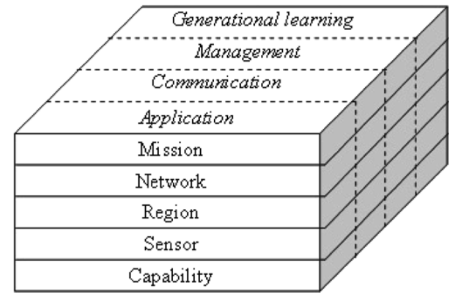

Fig. 2. Layered model.

service delivery. We propose a new five-layer service-centric model based on the above stated assumptions.

Fig. 1 shows a generic WSN deployment and mapping between layers and WSN components. The mission determines the overall functionality of the WSN. It describes a high-level goal of the WSN, i.e., what data is of interest and what types of services are needed. For a given mission, a set of services is provided. A service includes data gathering, aggregation, and processing from large areas of the WSN. Since sensors are identified only by their regions, service related activities within a region are considered to be atomic. The service can be decomposed into a set of services, each limited to a single region and involving all active sensors in the region. The sender, requesting such a service, may be in the same region or outside that region. Requesting, performing, and replying to the service require communication between sensors. Each sensor has a set of sensory/control devices (capabilities). Those devices are described by attributes with a specified range of values and a specified resolution. For a given mission only some devices are needed. A change in the mission may require a change of sensor configuration.

The relationship between a mission and a corresponding sensor configuration can be explored to define a QoS objective for a WSN. The QoS at the mission level may be qualitative, or even fuzzy. However, QoS for lower layers can be much better defined using quantitative measures [9]. A mapping between the mission level QoS and the capability level QoS, created as a composition of four mappings between neighboring levels, provides performance metrics and measures for all layers. Such a mapping must work in both directions, from mission to capability and from capability to mission. A more detailed description of each layer of the service-centric model provides a foundation for discussion about performance metrics.

Within each layer, four different planes or functionality sets are available; application, communication, management, and generational learning. These planes do not constitute vertical segments in the model, but instead they group together similar functions. This grouping can be used as a reference point for mappings between layers.

The application set contains all functions necessary for raw data collection and processing in support of WSN services. The communication set supports messaging and data exchange functions that maintain network connectivity. The management set includes "housekeeping" functions that handle service access, authorization, and security in general, as well as reconfiguring the WSN based on change in mission parameters. The generational learning set handles transfer of data and knowledge from the current to the next generation of sensors. That provides a way to extend the lifespan of the WSN well beyond the lifespan of an individual sensor.

Fig. 2 shows the layered structure. There can be several WSN services provided at the same time, both for remote users (e.g., mission control) and field users (e.g., pervasive computing). Remote users access the services through the base station, while field users may communicate directly with a sensor, provided they have the same regional coordinates. These services can be provided as regular web services.

III. PERFORMANCE METRICS AND LAYER MAPPING

The mission of a WSN is defined by required services, duration, space coverage, and other service parameters like spatial, temporal, and value data resolutions, etc. These requirements translate into capabilities of the individual sensor nodes and the underlying communication infrastructure.

A. Layers

A capability can be defined as an unforgeable data structure for a specific resource, specifying exactly the access rights that the holder of the capability has with respect to that resource. Distributed operating systems, like Amoeba [8], use this concept also in connection with security and messaging. Each resource is represented by a numerical value within a defined range. The simplest example is energy. The initial energy value is $E_{\max}$. The sensor can be on or off (standby). Fig. 3 shows four possible scenarios. Scenario a) illustrates a situation where the sensor is constantly on until energy is spent at time t_1. Scenario b) illustrates a situation where the sensor is on until time t_0. The sensor is then on standby and the rate of energy consumption is reduced. At time t_1 the sensor is on again until its energy is spent at time t_2. Scenario c) illustrates a situation where the sensor is constantly on standby until its energy is spent at time t_3. A graph for any other scenario will be somewhere between these two extremes (shaded area in the scenario c). Scenario d) illustrates a situation when a new sensor is replacing the existing sensor (generational learning). In this case, a transition from old to new

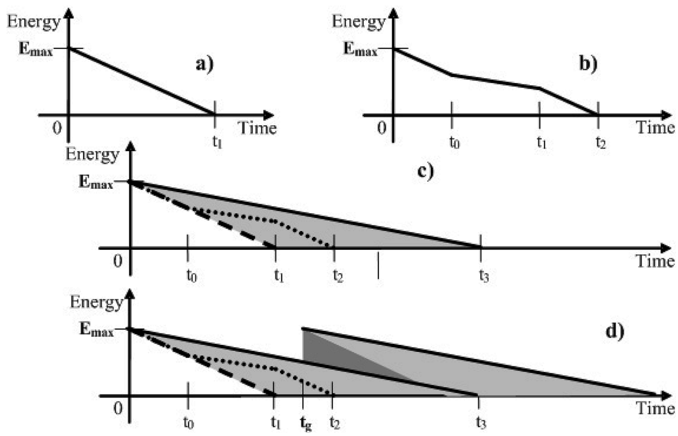

Fig. 3. Energy as a simple example of capability.

sensor (time period between t_g and t_3) introduces some potential ambiguity, especially if the old and new sensors overlap in time, i.e., work in parallel. The semantics of the generational learning determines the nature of the transition process. This simple example can be generalized to include a number of resources (including power) that can be on or off. The set of values for these resources define an N-dimensional resource space. A subset of this space defines the capability range, a set of all feasible uses of the sensor.

The example shown in Fig. 3 demonstrates how resource-centric models can be included into the service-centric model by focusing on the power as a single capability and then defining the mission solely in terms of energy consumption.

A mission can be defined in general in terms of a subset of an N-dimensional resource space, the mission range. Ideally, the mission range is a subset of the resource range. In a general case, only a part of the mission range will be included in the resource range. The percentage of the mission range covered by the resource range represents a simple QoS measure. The construction of the mission range is the result of a composite mapping based on mappings for each of the remaining four layers.

In case of a time-constrained mission, the maximum value for time is specified and creates a finite mission range (the resource range is finite due to a finite power supply). A QoS measure provides, given a time interval, what percentage of the mission range for that time interval is covered by the corresponding slice of the resource range. In case of the unbounded time, a QoS objective provides the amount of time the WSN can provide the desired percentage of coverage.

In general, a relationship between resources is determined by physical properties and functionality of a sensor. Such a relationship may be quite complex. A sensor mainly provides the following functionality [7].

- Turn a sensor device on and off: in case of power that means sensor is on or standby.
- Read a value from a device: periodically or on demand.
- Write a value to a device: periodically or on demand.
- Store a value (with timestamp) in memory: depends on memory size.
- Perform computation on values (and timestamps) in an array: min, max, average, sum, count, etc.
- Receive and send messages.

There are three types of messages that a sensor can handle.

- Service request/response that originates outside the WSN: a protocol is required (e.g., a bully algorithm) to determine which sensor(s) will perform the service.
- Service request/response that originates from a sensor processing the service request and is addressed to a set of regions. A protocol is required to determine which sensor will perform the operation.
- Service processing: a region-based broadcasting is used to exchange data.

In the simplest case, the constraints are linear and the resource range is a convex polyhedron in an N-dimensional space. In that case, linear or nonlinear programming techniques can be used to determine a (global) optimum for the mission objective, as "seen" by an individual sensor. The presence of many sensors with unknown coordinates and the distribution over regions makes this much more difficult. That is another reason why a resource based optimization may be insufficient and why it may be necessary to consider other factors like coverage density, probabilities (random sensor distribution), and region "longevity." The generational learning capabilities may significantly extend the lifetime of a WSN, thus, further deemphasizing resource based optimization.

A region represents a collection of sensor nodes with identical coordinates. As a consequence, region level services are based on the combination of results from all sensor nodes in the region. A network is a collection of addressable regions where a mission service is transformed to a set of region services.

B. Functionality Sets

One of the conceptual differences between the service-centric model and, for example, the OSI model, is that layering is done based on the structural hierarchy, going from an individual sensing device/capability within a sensor node, sensor, region, and WSN to the complete mission. The functional components, used as layers in the OSI model, are spread across each layer in the service-centric model. As a consequence, there is much more flexibility in the way that communication and management functions can be implemented. From the user's point of view, accessing a WSN is done by issuing a mission service request, either from a remote site or colocated with the WSN. In either case, the service is accepted using the application functionality set. Using the communication set, a sensor node is elected to coordinate service processing. The management set provides necessary authentication and authorization features, as well as coordination of multiple service requests at the same time. If the service requires an extensive time period to be processed (beyond the lifespan of an individual sensor) a generational learning set is involved. This approach makes the networking aspects of the system transparent to the user.

Data-centric models are subsumed in the service-centric model within application and communication functionality sets (with some management features). For example, directed diffusion (DD) is a data-centric protocol, where nodes are not addressed by their addresses but by the data they sense [10]. In the service-centric model the DD is represented through the region-based addressing and services that request specific data.

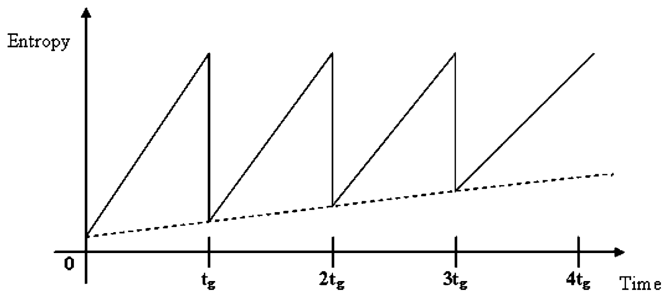

Fig. 4. Entropy change in generational learning.

The generational learning is a direct consequence of the limited lifespan of sensor nodes. A sensor, a region or the whole WSN evolves from generation to generation of sensors. Preferably, such change should be done for the whole network, within a time period significantly smaller than the sensor's lifetime. The WSN then has two distinct states, steady, and transition. From the information theory point of view, the WSN can be described by entropy. At the beginning of the steady state, entropy is at the lowest level. Over time, the entropy grows and once it exceeds certain threshold, a generation change starts. A part of information is transferred to the next generation and the cycle starts again. A consequence of generational learning is that the starting entropy of a cycle grows over time, thus providing a measure for learning capabilities of the WSN (Fig. 4).

The entropy change over time is also affected by the management functionality at the sensor level. A sensor that functions in the "slave" mode always responds to a request. The "active" mode allows the sensor to selectively respond and to some extent control the entropy rate.

C. Mapping Between Layers

Since sensors can have several capabilities, each capability has an identifier. The identifiers are the same across the WSN (sensors are assumed to be identical). A set of capabilities C can be specified as follows: $C = \{c_1, \ldots, c_n\}$.

The capabilities directly specify what can be measured, i.e., what are the attributes that are "visible" at the mission level. Since the mission level represents human interaction with a WSN, a corresponding formalism should be based on soft computing. Fuzzy logic is a natural choice [11]. The basic assumption is that for each capability at the capability level there exists a corresponding fuzzy linguistic variable X_i at the mission level ($\forall\, c_i \in C\; \exists X_i \in X$). The ranges of values are the same; the difference is that c_i has a crisp value, while X_i is described by fuzzy value described by a membership function (Fig. 5). This is needed for efficient mapping and performance measurement.

Linguistic values like HIGH, LOW, MEDIUM, and modifiers like VERY provide a formalism to create value for X_i. Once a corresponding membership function is determined, a defuzzification procedure [11] provides a crisp value for the corresponding c_i.

This simple mapping between capability and mission levels is a foundation on which mappings and formalisms for the remaining three levels are derived. These formalisms are strongly dependent on the type of operations performed at the sensor level. Any operation at the region and the network level is, in fact, performed by a sensor so there is a strong dependency.

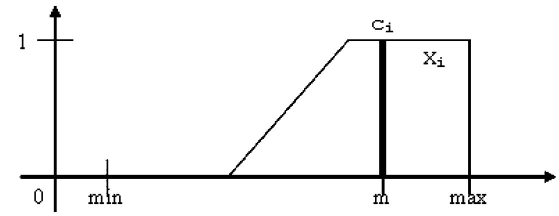

Fig. 5. Crisp and fuzzy values.

Considering a function of sensor as a collector and disseminator of data, data filtering must be present. As a consequence, the minimal set of operations consists of the following.

- Capability manipulation: MEASURE, STORE, RETRIEVE.
- Data processing/filtering:
  - — Relational operations: comparison between two values.
  - — Simple arithmetic operations.
  - — History operations: MAX, MIN, AVERAGE, SUM.
- Data dissemination: broadcast and unicast (region based).

This set of operations can be specified using a context-free grammar or Backus–Naur Form (BNF) grammar, where a set of rules define a sequence of operations performed with a given start symbol (e.g., a received message). The same reasoning can now be applied to region and network levels. The services at that level are performed by a sensor node and therefore have the same characteristics. This self-similarity provides for a relatively simple way to "reuse" the BNF grammar at sensor, region, and network levels. What it boils down to is that a mission service request is defuzzified and represented as a one or more network level services. These services are starting symbols for the network level BNF grammar. A formal derivation process creates sentences with terminal symbols services at the region level. Switching to the region level BNF grammar means that all symbols in the network level sentence are starting symbols at the region level. Therefore, after three levels of recursion, a starting symbol at the network level has generated a very long sentence, or a large set of sentences at the sensor level.

D. WSN Presentation

There are still many hurdles to overcome to realize the full capability of WSNs. One major area is interpretation and management of sensor data. A large WSN has the ability to create voluminous amounts of data in near real time. Human interpretation of this data requires sophisticated tools.

The tools used for information visualization are capable of examining large datasets with many dimensions over a wide variety of data types. However, the first task is to identify what facets of information visualization could be applicable to WSNs. Typical issues include topology and communication path discovery, individual sensor status and historical data review.

Most of the available WSN simulation tools use a two-dimensional (2-D) based user interface [12]. A major disadvantage of 2-D visualization is screen clutter when there are large amounts of data. Communication paths are represented as lines and when there are large numbers of them, they overlap obscuring information. Two-dimensional visualization also does not display information about the environment in which the sensors are deployed. Sensors are very tightly integrated with their environment especially when they are deployed to monitor ground vibrations, enemy tracking, ocean depth monitoring, etc. In these cases, terrain information can account for much of sensor behavior. If sensors are deployed n terrain that is hilly or if sensors are highly mobile, reliable communication paths may not exist for communications. In such a case, lack of data from such a sensor may be misinterpreted as node failure in a 2-D visualizer that displays only a flat geographical map.

These limitations can be overcome by the use of a more visually intuitive and realistic tool using three-dimensional (3-D) modeling and visualization techniques. A 3-D visualization tool can be conceptualized at two levels of detail. A simple visualization tool replaces the 2-D components in a 2-D visualization tool with corresponding 3-D representations. A more elaborate tool visualizes the WSN as a virtual environment (VE). Navigation is performed based on location, time and services. Services can be individually selected or grouped based on the layer and the plane of interest.

The layer grouping (Fig. 2) corresponds to a level of details used for visualization.

- Mission: Presents a general status of the mission using the outline of the geographical location (terrain) where the WSN is located. The displayed information shows the status of a currently processed mission service(s).
- Network: Displayed as a collection of regions. Network traffic among regions indicates the overall level of activities in the WSN.
- Region: Individual nodes and traffic among nodes in a region are visible.
- Sensor: Individual sensor state and characteristics are shown.
- Capability: Individual sensor capabilities are shown.

The functional grouping is represented as a collection of overlapping visual components. A user can view any combination of layers and planes. The "slicing" of the WSN in these two dimensions (layers and planes) is a powerful visualization paradigm that can provide better understanding of the WSN. In addition to the location-based view, the user can, for example select the communications plane at the region level, the application plane at the sensor level or some combination of such "slices." This provides for a "service-based" visualization.

IV. Case Study

A simple case study is used to present some aspects of the service-centric model. A WSN is deployed to measure temperature. Each sensor node has a temperature sensing device specified by its temperature range, resolution, and sampling frequency. The device also has a memory of the hundred last readings. Sensors are initialized and deployed so that they measure temperature in the 0–100 F range with resolution of 0.1 F. Temperature measurements are taken every minute. A service request at the mission level is represented in a vague or fuzzy way. Consequently, a fuzzy based approach is a viable option. In a general case, for each of the capabilities at the sensor level, a fuzzy variable is defined with a set of corresponding linguistic values and modifiers. An example of a mission service request is

```
WHERE IS TEMPERATURE VERY HIGH LATELY?
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In this example, TEMPERATURE is a fuzzy variable, HIGH is a linguistic value, and VERY is a linguistic modifier. Time is also considered a fuzzy variable. The difference is that the time range may be unlimited so most of the linguistic values are defined relative to the current time, like LATELY in this case. The fuzzy values are defined in terms of membership functions. A membership function has value between 0 and 1 over an interval of crisp values.

Most of the mission requests are general in nature and should be broadcast to all regions. In this case, a fuzzy service request is mapped to an SQL-like query. A defuzzification takes place so "HIGH TEMPERATURE" becomes "$> 90°$" and "LATELY" becomes "< 10 min." The network service request becomes:

```
FIND REGION
WHERE temperature > 90
AND time < 10.
```

Such request may be broadcast by the base station, or alternatively, a sensor node can receive the request and forward it to the base station which will then broadcast it. The defuzzification process is performed outside the WSN. However, if sensors have some fuzzy processing features, such processing can be embedded into the network. The network service request will be received in all regions. One of the sensor nodes in the region becomes the managing node for that service. All other sensor nodes in the region automatically answer the second part of the network service query. At the region level, all nodes are processing the region service request:

```
FIND sensor
WHERE temperature > 90
AND time < 10.
```

At the sensor level, each sensor identifies temperature capability and its value 90 and the time value of 10. The current value and all values in the memory with a timestamp difference of 10 min less from the request's timestamp are checked. The sensor service provides an answer (true or false) to the query:

```
temperature > 90
AND time < 10?
```

At the capability level, the sensing process will be performed periodically and the result of measurement will be stored (with a timestamp) in a memory. The content of the memory can be retrieved as needed. The capability level services include:

```
MEASURE temperature
STORE temperature, timestamp TO MEMORY
RETRIEVE temperature, timestamp FROM MEMORY
```

The sensor uses the RETRIEVE capability service to scan the memory and provide a sensor service response (yes/no). The coordinating node waits for such messages within a given time period (timeout). If any yes response is received from sensors, the coordinating node sends a region service response

TABLE I
EXAMPLE OF FIVE LEVELS OF SERVICES

Level	Service Request	Service Response
Mission	WHERE IS temperature VERY HIGH LATELY?	area
Network	FIND region WHERE temperature > 90 AND time <10	region list
Region	FIND sensor WHERE temperature > 90 AND time < 10	region
Sensor	temperature > 90 AND time < 10?	true/false
Capability	MEASURE temperature temperature	temperature
	STORE temperature, timestamp TO MEMORY	temperature, timestamp
	RETRIEVE temperature, timestamp FROM MEMORY	temperature, timestamp

indicating region coordinates to the base station (network level). The base station waits for such messages within a given time period (timeout). It collects all region coordinates and then sends a network service response providing a (possibly empty) list of regions. The region list is used to determine the affected geographical area which is a response to the original mission service request. A summary of five levels of service is provided in Table I.

In this simple example the time period of 10 min is well within memory and power range of a sensor. As a consequence, most of activities are based on application and communications functionality sets. However, if defuzzification is such that LATELY becomes < 120 min, the sensor's memory (100 readings or 100 min) is no longer sufficient to support the mission service. As a consequence, the WSN uses the management plane so that a flag/register in a sensor node is used to indicate the measurement for period from 120 to 100 min in the past. The maximum temperature for that period would be sufficient to provide support for the mission service. If defuzzification is such that LATELY becomes < 10 days, and if the expected lifetime of an individual sensor is less than ten days, the generational learning plane is used. The maximum temperature over the lifetime of a sensor will be transferred to the next generation of sensors in that region. The provided case study is greatly simplified and provides an illustration of the service-centric model, rather than detailed description. However, the concepts of services, levels, and functionality sets (planes) are demonstrated.

V. CONCLUSION

The service-centric WSN model provides a general and flexible framework in which various more specific WSN models can be represented and evaluated. The key benefit is a clear separation between the high-level purpose of the WSN (mission services) and the low-level hardware specific capabilities of an individual sensor node (capability services). A mapping between mission and capability layers, created as a composition of mappings between intermediate layers, provides formalism for a service-centric description and evaluation of the WSN. Generational learning, combined with the support for mission change, allow for change in available services. The effects of such changes can be studied using formalism developed for each layer and the corresponding mapping between neighboring layers. Our current research is focused on the application of the service-centric model and the development of service-centric software architecture and a simulator. The simulator uses a plug-in-based architecture to allow dynamic configuration of individual layers and functionality sets within a layer. That will provide a foundation for better understanding of how to interconnect a group of WSNs to function as an integrated WSN system.

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