Internet and Distributed Computing Advancements:

Theoretical Frameworks and Practical Applications

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Chapter 8
Clustering in Wireless Sensor Networks:
Context-Aware Approaches

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ABSTRACT

Applications of Wireless Sensor Networks (WSN) have been expanded from industrial operation to daily common use. With the pace of development, a good number of state-of-the-art routing protocols have been proposed for WSN. Among many of these protocols, hierarchical or cluster-based protocol technique is adopted from the wired network because of its scalability, better manageability, and implicit energy efficiency. In this chapter, the authors have surveyed Low Energy Adaptive Clustering Hierarchy, Power-Efficient Gathering in Sensor Information Systems, Adaptive Periodic Threshold-Sensitive Energy Efficient Sensor Network, and Hybrid Energy-Efficient Distributed Routing Protocols. These protocols exhibit notable characteristics and advantages compared to their contemporaries. Again, context aware computing and applications have been greatly emphasized in recent articles by renowned technologists. This approach is considered as a momentous technology that will change the way of interaction with information devices. Accordingly, context aware clustering technique carries a great deal of importance among WSN routing protocols. Therefore, the authors have investigated noteworthy context aware routing protocols such as: Context Adaptive Clustering, Data-Aware Clustering Hierarchy, Context-Aware Clustering Hierarchy, and Context-Aware Multilayer Hierarchical Protocol. Their investigation and analysis of these protocols has been included in this chapter with useful remarks. Context awareness is considered an integral part of Body Sensor Networks (BSN), which is one kind of WSN. Thus, the authors have also discussed issues related to context aware techniques used in BSN.

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Figure 1. Sensor nodes of WSN. (Source: Crossbow Inc. [left & right], Sentilla Corp. [middle])

WIRELESS SENSOR NETWORKS (WSN): AN INTRODUCTION

Advancement of Micro-Electro-Mechanical Systems (MEMS) and wireless networking has led to a sort of revolution in the development of sensor technology. Sensor nodes are getting smaller in size and smarter in functionality. Each of these sensors generally includes one or more sensing units, a data processing unit and a wireless communication unit. The sensing unit or units of a sensor node measure ambient conditions of surrounding and transform those into an electrical signal. Such ambient conditions may be temperature, humidity, acoustic, seismographic data of the environment, or may be motion, direction of living beings. Based on application and capability, that electrical signal is processed to reveal some vicinity properties or compressed to reduce communication overhead. Then, the communication unit wirelessly sends such data towards a central control directly or via other sensors. This central control is often regarded as a sink or base station. In this way, these sensor nodes form an ad-hoc network which is referred as Wireless Sensor Networks (WSN).

Some physical characteristics of sensor nodes often differ depending on applications. However, a common characteristic of WSN is that the deployment is usually in physical environment. As the sensory range is quite limited, a large number of sensors are needed to be deployed to get complete area coverage or accurate information. Regarding the size and weight of sensor nodes, they are needed to be as small as possible. There are commercially available sensors the size of a matchbox (Crossbow Inc., 2010) or even the size of a coin (Crossbow Inc., 2010) as shown in Figure 1. In the military domain, cheap and cubic centimeter sized sensor nodes are aimed to be developed which can be heavily deployed in larger areas (Warneke, et al., 2001). And, the weight is becoming more suitable for easy deployment and longer sustainment. For commercial applications, cost is a major issue. Costs already have fallen sharply compared to products a decade ago. With rapid technological advancement, it is expected that sensors will be cheaper and more affordable in the near future.

One of the key characteristics of sensor nodes is that they are energy constrained. Typically sensor nodes rely on finite energy sources like batteries. Due to the massive numbers deployed and remote, unattended positions, replacements of batteries are quite impossible. Harvesting energy from the environment is currently a promising but under-developed research area. Moreover, expectancy of longer lifetime of sensor nodes has put researchers to work on every possible aspect of sensor nodes in gaining energy efficiency. Other key characteristics include limited computation and communication capability. The processing unit usually has an 8-bit to 32-bit micro-controller with 256 Kbytes to 512 Kbytes programmable flash. Therefore, there are limitations in the amount of data to be processed and processing criteria. Some existing sensors use 2.4

GHz or 916 MHz channels and promise to provide a communication range between 75 to 150 meters outdoors and 20 to 30 meters indoors. However, in actual deployment, such communication range cannot be obtainable due to different overheads (Kim, et al., 2007). Another key issue is to make WSN data available to the human observers or control applications. Often it is possible by connecting WSN to a fixed communication infrastructure via wireless LAN, satellite network or cellular network. To do this, one or more gateways are necessary to carry the inter communication. Sometimes, one of the sensor nodes acts as a gateway or in other cases, specialized gateway devices such as PDAs and laptops are used. In either case, gateways have two interfaces, one with the WSN and another with the communication infrastructure. As gateways are expected to have more energy and communication capability, they sometimes carry the additional burden of the WSN. Due to the advancement of WSN, applications have been expanded to numerous diverse fields (Arampatzis, et al., 2005). These applications can be classified into two broad categories (Culler, et al., 2004), namely, monitoring space and monitoring targets. The first category includes applications such as habitat monitoring, precision agriculture, electronic surveillance, and intelligent security systems. The latter category is comprised of applications like object tracking, structural monitoring, terrain mapping, etc. There is another type of category that is hybrid WSN. In Hybrid WSN, interaction between targets and with surrounding environment facilitate in emergency management such as in nuclear plants, mining, etc. Some major applications of WSN are described below:

Environmental monitoring: WSN can be deployed to gather environmental data from a specific geographic region. Already there are many such deployments. For example, WSNs have been deployed in Ecuador to monitor volcanic activities at different times (Allen, et al., 2006).

Security applications: Key public infrastructures, nuclear power plants can be secured by integrating networks of video, acoustic, and other sensors. Due to availability and affordable price, smaller versions of such security systems are becoming more and more popular.

Military applications: Early WSN research actually started on the military domain first. In this domain, there are some wide categories of usage such as battlefield coordination and tracking enemy vehicles (Abdelzaher, et al., 2004).

Medical and health monitoring: In health care applications, individual sensors were used to get patients' physiological information such as electrocardiograms and electroencephalograms in real time. Another significant use in health care is providing basic medical services for elderly patients by collaborating between WSN and other appliances.

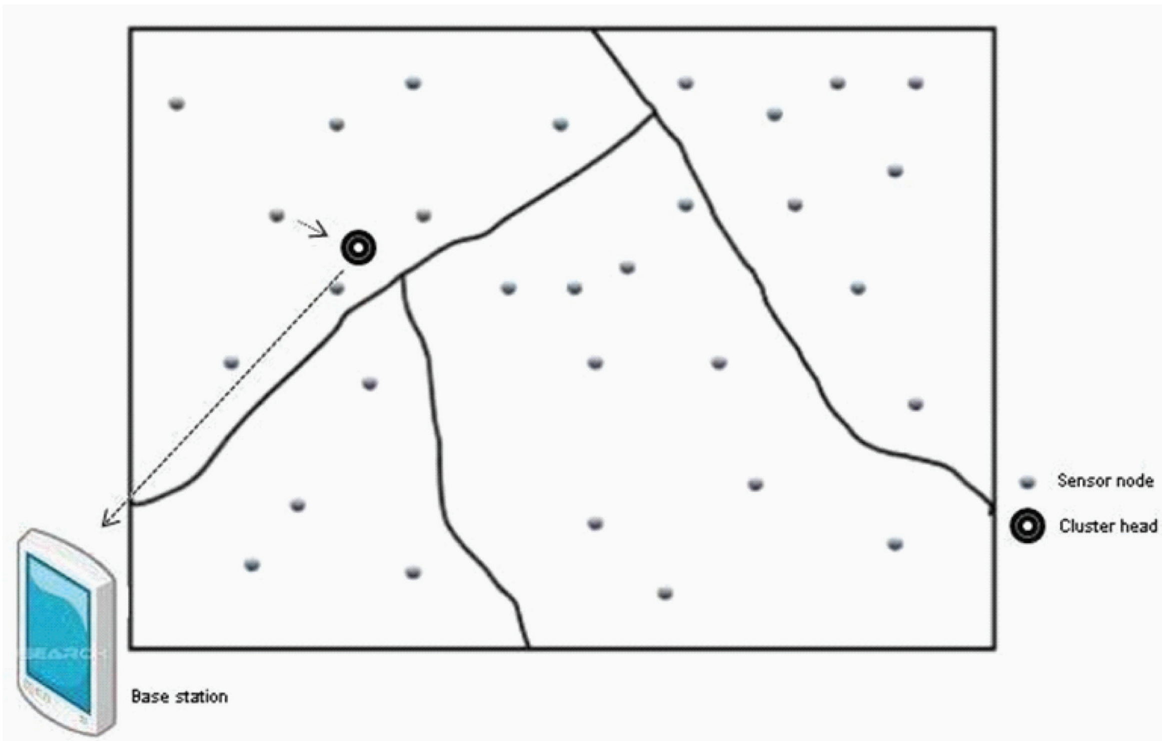
Industrial control management: Industrial applications have gotten much attention because WSN can be used as a means of lowering cost, improving machines, and providing better maintainability. Sensors can be implemented within and inside the machineries where human access in not possible.

Intelligent environment: WSN is applicable not only outside or as independent but also can be within existing systems. For example, motor vehicles are now manufactured with a number of sensors in components like the accelerator pedal and brake pedal that form a network to deliver precise vehicular status information.

ROUTING IN WSN

Routing in WSN is quite challenging due to its inherent constraints and basic characteristics that

Figure2. A typical cluster-based wireless sensor network scenario



distinguish WSN from other wireless networks. The absence of a global addressing scheme, characteristic of data flow, a single destination, and resource constraints have made routing a difficult task. A handful of routing protocols have already been proposed for WSN. These protocols can be broadly categorized into four different types (Al-Karaki & Kamal, 2004), namely, data centric, hierarchical or cluster-based, location-aware, and data flow or Quality of Service (QoS) based.

Hierarchical or Cluster-Based Routing

In a hierarchical routing, sensor nodes are assembled into groups called clusters (Figure 2). Every node in a cluster has usually a single point of communication that is a Cluster Head (CH). Sometimes a normal node performs this duty or higher residual energy nodes are assigned. Such a CH can be elected by the sensor nodes or pre-assigned by the network designer. Tasks of a CH include the processing of member node's data and long-range communication. CHs usually communicate with the Base Station (BS) directly or in multi-hop fashion. Cluster membership may or may not change during network lifetime. In some cases, CHs are further grouped for a higher level hierarchy.

The hierarchical or cluster-based protocol technique is originally derived from the wired network to wireless network because it offers a number of advantages. Such as:

1. Clustering keeps routing table of individual nodes quite short by localizing route setup within clusters (Akkaya, et al., 2005).
2. Clustering technique preserves bandwidth and avoids congestion by managing inter-

cluster communication only through cluster heads.

3. It is easier to maintain topology as nodes usually communicate with cluster head only. (Hou, 2005).
4. Cluster heads can aggregate a packet based on defined criteria. Thus, this technique reduces redundant packets (Dasgupta, et al., 2003).
5. Special node management strategies such as node activity optimization or scheduling scheme can be implemented which can make nodes energy efficient.

The formation of hierarchical structure significantly increases the overall system scalability, system lifetime, and energy efficiency. The activities of such protocols can be layered into two phases–first, selection of cluster heads and cluster boundary and second, routing activity. Among many proposed cluster-based protocols, Low Energy Adaptive Clustering Hierarchy (Heinzelman, et al., 2000), Power-Efficient Gathering in Sensor Information Systems (Lindsey & Raghavendra, 2002), Adaptive Periodic Threshold-Sensitive Energy Efficient Sensor Network Protocol (Manjeshwar & Agrawal, 2002), and the Hybrid Energy-Efficient Distributed Clustering (Younis & Fahmy, 2004) routing protocols have notable characteristics and advantages. Below three major hierarchical protocols are discussed.

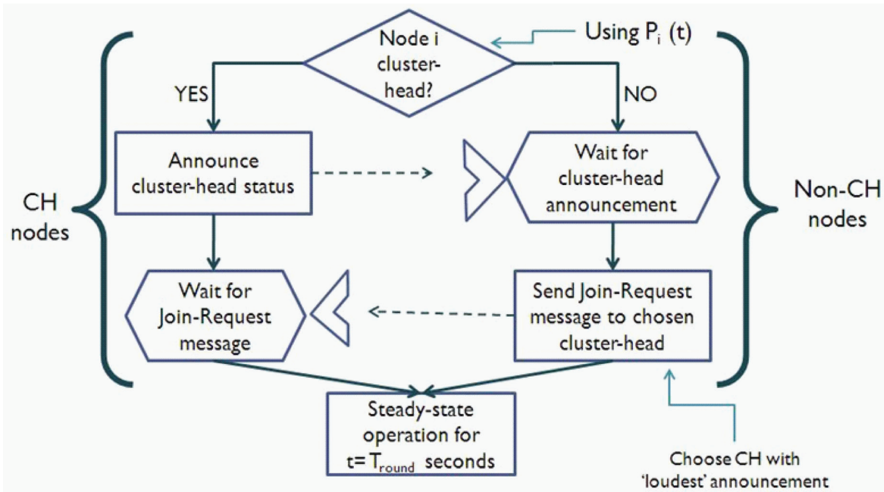
Low Energy Adaptive Clustering Hierarchy (LEACH)

LEACH (Heinzelman, et al., 2000) is the first hierarchical protocol in WSN. In many recent studies, it has been considered as the benchmark for other protocols. It has some distinctive characteristics like self-reconfiguration, adjustment of communication range according to distance, schedule of data transmission of individual nodes, etc. Moreover, unlike most proposed protocols, LEACH has been implemented on actual hardware (MICAz sensor nodes) (Obashi, et al., 2007). It has some assumptions like fixed-base station location, energy constrained homogeneous nodes, and predetermined ratio of cluster heads among all nodes. The operation of LEACH is separated into a series of equal length time spans. In each of these time spans, cluster head selection and cluster formation and scheduling procedures are completed, respectively, at the very beginning. Cluster heads are selected based on a probabilistic value satisfying the condition that those nodes have not played that role previously. Upon receiving broadcasted advertisement messages from a single or multiple cluster heads, a node sends a joining declaration to the nearest cluster head. Cluster heads then create a TDMA schedule and notify its member nodes. This distributed cluster formation technique is depicted in Figure 3. The following data transmission phase has the larger chunk of each span, which is also divided into a number of equal frames. In each frame, there is a slot for every member node. Member nodes send data to cluster heads at their slot time. The cluster head aggregates the data and send to the base station. Despite significant advantages, LEACH also has to deal with some drawbacks such as:

- Cluster head is selected based on probabilistic value. So there is a possibility that cluster heads will be repeatedly selected from one part of the network.
- Cluster head role is not uniformly distributed. Thus, some of the nodes might be out of service quickly.

To overcome these, LEACH-C (Heinzelman, et al., 2002) was proposed imposing centralized control. Nevertheless, none of these two versions is concerned about the context of the environment. The framework of LEACH has been utilized in the development of other protocols (Lindsey & Raghavendra, 2002; Muruganathan, et al., 2005). Power Efficient Gathering in Sensor Information System (PEGASIS) has been proposed by Lind-

Figure3. Distributed cluster formation in LEACH



sey & Raghavendra (2002) that uses a greedy algorithm to construct a chain. Each node only transfers packets to the closest node on the same chain. But it inherits limitations of the multi hop model such as excessive delay for distant nodes. Again, a single leader can be a bottleneck for the whole network.

Threshold-Sensitive Energy Efficient Sensor Network (TEEN) and Adaptive TEEN (APTEEN) Protocol

Two protocols namely TEEN (Manjeshwar & Agrawal, 2001) and APTEEN (Manjeshwar & Agrawal, 2002) were proposed specifically for time critical applications. TEEN protocol forms clusters with closer nodes in a data centric approach. This approach continues until the BS has been reached. After cluster formation, CHs broadcast two thresholds, namely a hard threshold and a soft threshold. The hard threshold is the minimum possible threshold value of Sensed Value (SV). On the other hand, the soft threshold is the small change in SV that triggers the sending of SV. Thus, these thresholds reduce the number of transmissions significantly. Moreover, users can set the tradeoff ratio between energy efficiency and data accuracy. Whenever CHs are changed, new threshold values have to be broadcast. The main drawback of TEEN is, if the threshold values are not received, nodes are out of communication. Again, this protocol is not very suitable for continuous monitoring, such as habitat monitoring. To overcome these drawbacks, TEEN was extended as APTEEN which combines both proactive and reactive policies. APTEEN CHs broadcast additional parameters such as Time Division Multiple Access (TDMA) schedules, count time, and desired attributes of the user's query. TDMA schedules contain a specific slot for each node. And, the count time is the maximum period between two successive SV reports. If the count time exceeds, the node will send the SV again whether the soft threshold has been reached or not. Despite the extension, there are some drawbacks to these two approaches such as overhead of threshold functions, complexity in multilevel hierarchies, and complicated attributed queries.

Hybrid Energy-Efficient Distributed Clustering (HEED)

HEED is a multi hop hybrid clustering protocol that utilizes residual energy information and node density to balance energy consumption within the network. This protocol has aimed to achieve longer network lifetime and lesser control overhead. HEED follows strict procedures to map nodes within non overlapping clusters. Energy consumption of each node is assumed not to be uniform. The protocol functionality is organized into three phases. At the initialization phase, the percentage of CHs has been set based on the residual energy to limit the number of CH announcements. In the subsequent repetition phase, every node goes through a number of iterations to find a CH with the least communication cost. Otherwise, the node declares itself as a CH. During this iterative state, a prospective CH continues with a 'tentative' status until a lower cost CH has been found. At the finalization phase, this status is changed to 'final' if the node can become a CH. Other nodes set their status appropriately. Thus, through these three phases, distributed CHs with non overlapping boundaries are selected based on residual energy and transmission cost. HEED protocol performs better in cases of longer network lifetimes. However, limited parameters in CH selection sometimes may impose constraints on the total system.

CONTEXT-AWARE APPROACHES IN WSN

The term "context-awareness" was introduced to the computational world more than a decade ago (Schilit, et al., 1994). Here, 'context' was referred to as location, identities of nearby people and objects, and changes to those objects. In the foremost application, software had been developed that could examine and react to an individual's changing context. The main purpose of such context awareness was to identify an individual's location, companion, and surrounding resources. Generally, context-awareness refers to linking changes in the environment with computer systems. This context awareness has not been utilized in WSN until recently. A number of cluster-based routing protocols have been proposed based on the context aware approach. Moreover, this concept has gained much attention in other viable fields such as context aware computing and applications. In a keynote speech in September, 2010, at the Intel Developer Forum (Intel Newsroom, 2010), industry giant Intel's Chief Technology Officer greatly emphasized context aware computing as it will fundamentally change the nature of interaction with information devices. Such context aware computing can be defined as a system if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task (Dey, 2001). Thus, context aware clustering carries a great deal of importance among WSN routing protocols. Exploitation of such context awareness in a WSN routing protocol has to meet some prerequisites during protocol development. These requirements include:

1. Autonomous or manual selection of context range for clustering has to be intelligent enough so that clusters are mutually exclusive and equally scattered as much as possible throughout the area.
2. If contextual data is not changing or changing by a negligible value, nodes should be aware of such patterns and utilize these patterns in sensor data traffic.
3. In case of creating multiple hierarchies based on context information, cluster heads have to be carefully selected to avoid multiple duties. Otherwise, multiple duties can be cause for early energy exhaustion of some nodes.
4. Context aware protocols have the competitive advantage of having data resemblance within a cluster. Thus, utilization of advances in node data processing techniques such as data fusion and data aggregation at the cluster heads can be considered an essential requirement of a smart context aware routing protocol in WSN.

Among proposed context aware protocols of such type, Context Adaptive Clustering (Jin & Park, 2006), Data-Aware Clustering Hierarchy – DACH (Wu, et al., 2008), Context-Aware Clustering Hierarchy (Haque, et al., 2009), and Context-Aware Multilayer Hierarchical Protocol (Haque, et al., 2010) are noteworthy for their features and applicability. Below these protocols are described briefly:

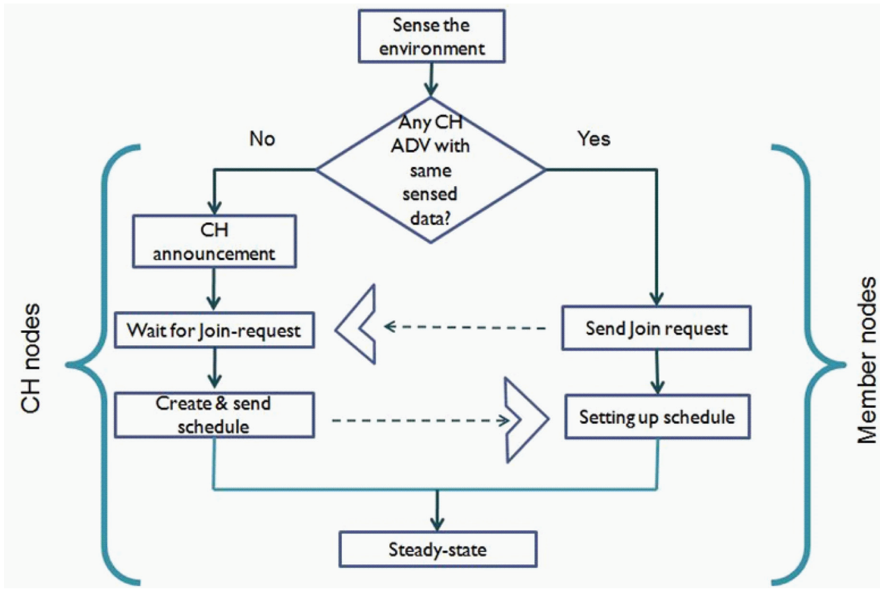
Context Adaptive Clustering (CAC)

CAC has been proposed with the aim for efficient data aggregation. CAC presents a simple, transparent, and decentralized algorithm and utilizes the high data correlation within clusters. In cluster formation, the number of initial clusters, tolerance parameter (range of context), and a threshold for re-clustering are manually determined. Authors have proposed a clustering mechanism that strives to form clusters of sensors with similar output data within the bounds of a given tolerance parameter. If a cluster head detects context value beyond the threshold, re-clustering is initiated. During the re-clustering operation, nearby nodes become a cluster head if they are on the list and broadcast re-clustering commands to their neighbors. In the other case, the nearby node joins if own context match with the new cluster head. If none of these two conditions matches, it stops propagating the re-clustering command. In the later data transmission phase, cluster heads aggregate data received from the nodes and send it to the base station. As clusters are formed with nodes gathering similar data, the simple data aggregation technique works well without introducing large errors. An expected benefit is to reduce energy consumption and to prolong network service life. This protocol shows impressive performance in an environment where the change of the surrounding context is quite gradual. On the contrary, the cluster head role has not been distributed, which might cause energy exhaustion of some nodes early. Again, there is no distinctness between the set-up and data transmission phase. Besides, if the environmental phenomenon is changing rapidly, the algorithm might not be suitable. Thus, this algorithm's applicability is limited to certain fields only.

Data-Aware Clustering Hierarchy (DACH)

In DACH, authors have proposed a protocol that is data-aware, and cluster formation is based on distance between nodes. The protocol constructs a multilayer hierarchical structure and utilizes data similarities within clusters for query processing. Moreover, 'discrimination' functionality of data mining is effectively used in querying. It operates in three phases. At the initialization phase, the base station generates time series based on received data from all nodes. Based on time series, base station then calculates discrimination of each pair sensors. Lowest discrimination constitutes level 0 of the hierarchy of the structure. If the discrimination is higher than the specified threshold, nodes are included in the next higher level of the hierarchy. In the setup phase, base station receives energy information and generates paths in a bottom-up way. In this process, cluster heads are selected with highest residual energy. The data transmission phase is quite identical to previous two protocols. DACH shows better performance in the simulation. However, a closer look at this protocol reveals some unattended issues. In the selection of high residual cluster heads, the energy information must be shared among every node. Without having an active routing protocol, dissemination of such information is quite impossible unless being broadcasted. Broadcasting this information might significantly increase the traffic and ultimately will decrease energy efficiency. Moreover, the multilevel clustering hierarchy is not optimized in selecting cluster heads. As a result, in certain situations the cluster head role might be played by the same node in multiple levels, which may cause faster depletion of residual energy.

Figure4. Clustering algorithm in CACH



Context-Aware Clustering Hierarchy (CACH) and Context-Aware Multilayer Hierarchical Protocol (CAMHP)

CACH has been proposed with the aim to attain maximum energy efficiency. It forms clusters entirely based on the context of the environment and distribute cluster head role across the network symmetrically (Figure 4). In CACH, lifetime of the network is divided into some rounds like LEACH. After the initial deployment, nodes enter into the setup phase. Each node enlists itself to a cluster by exchanging advertisement messages with context information and join request messages. CH of each cluster is decided based on the earliest message propagation role among nodes. Next, CH sends a schedule for the current round to member nodes in a unidirectional manner. In the latter steady operation phase, each node sends its own data to the CH according to the slot time. In consecutive slots, upon sensing the environment, a node compares its current sensed value with the previous one. If there is no change in the value, the node does not send the data. CHs sequentially aggregate data from member nodes into a single packet disregarding the empty slot. This aggregated packet is sent to the Base Station (BS) directly. On this end, BS keeps track of each member node in every cluster. So, an aggregated packet is being extracted and checked for any missing member node data. If so, BS assumes the current data content is the same as the previous one and continues its operation with the previous data. Upon forming a cluster in later rounds, a CH checks the role history of every member node. If all nodes within a cluster have already been a CH in previous rounds, this role history is erased; thus CHs become just like the initial stage. This technique ensures the CH role rotation that is responsible for uniform distribution of energy consumption across the network. Contrasting to other context aware protocols (Jin & Park, 2006, Wu, et al., 2008), CACH provides advantages like distinctive cluster formation, equal distribution of CH role, and data traffic optimization.

CAMHP is also context aware and utilizes a multilayer hierarchical structure to cover more area. After the initial deployment, nodes act the same as CACH for the selection of member nodes

Table 1. Comparison of context-aware protocol based on selected criteria

	CAC	DACH	CACH	CAMHP
Protocol objective	Efficient data aggregation	Energy efficiency + query accuracy	Energy efficiency	Energy efficiency + Area coverage
Degree of clustering	Double layer	Multilayer	Double layer	Tri layer
CH selection criteria*	Out of context threshold	Residual energy	Not been CH before**	Not been CH before**
CH role distribution	Random	Random	One after another	One after another
Inter-cluster topology	Multi hop	Multi hop	Single hop	Single hop
Query processing	No	Yes	No	No
Mobility	Minimal	Undefined	Quasi	Quasi

* All protocols in the table utilize context-aware approach.
** If all nodes within a cluster have already been CH, nodes that first declare becomes a CH.

and CHs. For super CH selection, member nodes check whether they have heard CH advertisements from all the CHs. If so, it enlists itself as a candidate node and again checks whether it has received any super CH advertisements or not. If so, the candidate proceeds with the duties of a member node. Otherwise, it declares itself as a super CH and broadcasts this message. This message is processed by the CHs only and assists them to identify the super CH. If a node has not heard CH advertisements from all the CHs, it proceeds with the normal duties of a member node. Thus CHs are hooked up with a single super CH to whom aggregated packets are sent. Duties of a super CH are same as CHs except it communicates directly to BS. CAMHP inherits all the advantages of CACH as well as covering more sensing area through additional hierarchy. However, in both CACH and CAMHP, the threshold for not sending sensed data in consecutive rounds is not well defined. Thus, prior measurement of environmental phenomena is needed before implementing these protocols. Moreover, in certain rounds, CHs with the farthest distance from super CHs or BSs were selected causing early energy exhaustion of those nodes. Thus, CH and super CH role distribution is not that effective sometimes.

Table 1 shows a comparison between CAC, DACH, CACH, and CAMHP based on selected criteria. These context-aware hierarchical protocols share a number of common characteristics such as cluster count and CH data aggregation. However, they have their differences in functionality and operation.

CONTEXT AWARENESS IN BODY SENSOR NETWORKS (BSN)

BSN has been on a peak of research effort in recent years due to the development of affordable sensors as well as urgency for early, accurate, and complete diagnosis. BSN, also known as Body Area Network (BAN), is one kind of WSN where sensors are wearable by humans. Typically BSN includes multiple miniature sensors that can measure the human body's physiological conditions such as blood pressure, temperature, glucose concentration, ph measurement, oxygen saturation level, etc. There is also a single Body Central Unit (BCU) or Local Processing Unit (LCU) that processes the sensory data, converts it to a readable format, and sends it to the health service infrastructure via Internet or cellular network (Ullah, et al., 2010). Compared to other types of WSN, BSN has some specific development criteria. As BSN is aimed to sense human body conditions, such sensing should be respectful and non invasive to human dignity as well as affordable and cost effective. Concurrent BSN research is dealing with a number of technical challenges like biosensor design, suitable power source, context awareness, and multi sensory data fusion (Lo & Yang, 2005). Among these challenges, context awareness plays a vital role for accurate and meaningful information extraction through BSN. Relying only on physiological information can often cause false detection due to motion artifacts and changes in the contextual environment. For example, a sudden heart beat increase may be due to jogging rather than cardiac arrest. Thus to acquire relevant information, context awareness must be incorporated with BSN.

Context Aware Techniques

To gather contextual information, classification of raw data is the first step. Raw data can be associated with a context profile through the means of user labels. Some classification techniques recognize context at a given instance in time and others utilize supervising layer to extract constant recognition of context. All together, context aware techniques can be categorized into three broad approaches (Korel & Koo, 2010):

Artificial Neural Network (ANN): Application of ANN in BSN is purely for clustering of sensed data. Generally two types of ANN are used such as: Kohonen Self-Organizing Map (KSOM) and KSOM with k-means. One of the notable advantages of using ANN is the capability of clustering despite the presence of noise in sensor data. Another advantage is inclusion of unsupervised training of input data. In the latter case, a BSN does not need to spend much time on training which makes BSN more feasible and adaptable in applications. There are numerous works on these two branches of ANN for utilization in BSN (Lagerholm, et al., 2000; Gao, et al., 2004; Thiemjarus, et al., 2006) and still ongoing to overcome limitations such as dealing with high dimension input data.

Bayesian Network (BN): BN is a directed graph model that can signify sensory data as random variables and directed arcs as their causual dependencies. BN follows an independence assumption between random variables that can promote higher accuracy in clustering. Advantages of using BN include computational efficiency, noise resiliency, and energy efficiency by feature selection. Researchers utilizing BN for deducing context in BSN have proposed systems based on either Naïve Bayes classifier (Korpipaa, et al., 2003; Tapia, et al., 2004) or BN with hidden node (Thiemjarus, et al., 2005).

Hidden Markov Models (HMM): In BSN context needs to be continually recognized throughout a time span not just at exact instances in time. With such requirements, HMM can be introduced at the supervising layer to build a model of context transition. Hence, HMM is more capable of modeling human behavior as it can recognize sequences of activities. The probabilistic model of HMM can also offer other advantages like handling of noisy sensor data and improved computational performance. Notable research works on HMM for BSN include Clarkson & Pentland (2000), Kautz et al. (2003), and Chen et al. (2005).

FUTURE SCOPE

Research on context aware routing protocols is a bit immature compared to other types of routing protocols of WSN. Therefore, many open issues still need to be addressed. Some key future scopes are described below:

1. As context-aware protocols are crucially dependent on different synchronous phases during operation, lightweight time synchronization is quite significant in real applications. Though, there are a good number of time synchronization protocols for WSN (Sundararaman, et al., 2005); yet there are still some critical open issues regarding accuracy, scalability, energy efficiency, and fault tolerance.

2. In the future, fewer nodes will be equipped with energy sources like batteries. Thus, it is expected that the majority of WSN nodes will rely either on powered mains or on energy harvesting. This will also profoundly affect any kind of routing design. Irrespective of routing protocol category, energy harvesting is definitely a significant challenge.
3. Actual deployment or real world implementation is quite important for WSN. Though simulation of protocols is an effective and reasonable way of testing, actual implementation can find many hidden design issues (Alippi, et al., 2008).
4. Prior measurement of environmental context for setting threshold is considered as an assumption in context aware protocols. Thus, there should be a suitable schemes to set and adjust threshold parameters upon initial deployment.

We have also discussed context awareness techniques in BSN. Future research issues in this domain include noise detection, adaptive learning, and appropriate feature selection (Korel & Koo, 2010). However, details of these issues are beyond the scope of this chapter.

CONCLUSION

In this chapter, we have first briefly focused on three prominent hierarchical protocols of WSN. As a recent trend, the context-aware technique has been applied in hierarchical protocols. Four such promising protocols are surveyed here and compared based on selected criteria. Designers of these protocols have discussed further development of their propositions in related publications. However, these protocols inherit various shortcomings which are concisely mentioned here. One of the most promising types of WSN is the BSN. Thus, context aware techniques of BSN are also briefly discussed according to the scope of this chapter. It is expected that continual advancement of the context-aware approach will address the future issues and pave the way for smooth deployment of WSN in real world applications.

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KEY TERMS AND DEFINITIONS

Body Sensor Networks: A specific class of WSN is Body Sensor Networks (BSN) that represents an emerging platform for many human-centered applications, spanning from medical to sports performance monitoring, gaming, and social networking.

Context-Aware Clustering: It is a clustering technique that is used in WSN routing protocols. Here, context' is referred as location, identities of nearby people and objects, and changes to those objects.

Context-Aware Computing: Context aware computing and applications have been greatly emphasized in recent articles by renowned technologist. This approach is considered as a momentous technology that will change the way of interaction with information devices.

Wireless Sensor Networks: Wireless Sensor Networks (WSN) are inherently distributed in nature and distributed across the globe. A WSN consists of spatially distributed sensor nodes to cooperatively monitor physical, environmental, or human conditions such as temperature, sound, vibration, pressure, motion, heart rate, and blood pressure.