Feasibility Analysis of Clustering Routing Protocols for Multipurpose Sensor Networking

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***Abstract* - Recent advances in wireless sensor technology have led to the evolvement of new protocols specially designed for wireless sensor networks. Current wireless sensor network routing protocols are based on the assumption that all sensor nodes are monitoring a single global event. However, in many scenarios, it is desirable to use a single sensor network to monitor multiple events. This will not only reduce the cost of deploying and administering the sensor nodes but it will also improve the management and efficiency of the entire sensor network. Cluster-based routing protocols for large-scale wireless sensor networks are more suitable for multipurpose sensor networking scenario because clustering minimizes the number of messages that are propagated throughout the network whenever an event is sensed. In this paper, an investigation of selected clustering routing protocols for wireless sensor networks is presented together with a highlight of their key features and their ability to adapt to multipurpose sensor networking.**

Index Terms: Clustering Routing Protocols, Multipurpose Sensor Networking, Network Reliability, Energy Efficiency

I. INTRODUCTION

Advancements in micro-electro-mechanical systems technology, wireless communications and digital electronics have led to the proliferation of smart and miniaturized sensors which leveraged the idea of wireless sensor networks and their versatility for remotely monitoring events [1], [3]. Sensor networks contain hundreds or thousands of sensor nodes that work in a collaborative manner to achieve a sensing task. Wireless sensor network architecture comprises of a sink and other sensors. These sensors communicate with each other to forward messages to the sink, which is the entity interested in monitoring one or more event in the network [1], [3].

Sensor networks have only a limited amount of energy available to them as they derive their energy from an in-built battery and not from a constant power supply. Moreover, because these nodes are deployed in places where it is difficult to replace the nodes or batteries, it is desirable to increase network lifetime [1], [2].

A large number of routing protocols have been recently developed for wireless sensor networks [1]. Current protocols are based on the assumption that all sensor nodes are monitoring a single global event. However, in many scenarios, it is desirable to use a single sensor network to monitor multiple events [2]. Clustering routing protocols have been developed with the aim of conserving energy by reducing the traffic toward the sink and they are more suitable for multipurpose sensor networking scenario [3], [4], [5], [6], [7], [8]. This is because earlier research work has shown that clustering routing protocols possess better energy consumption and performance than flat network topologies in wireless sensor networks [3].

In this paper, an investigation into the feasibility of selected clustering routing protocols for multipurpose sensor networks is presented. This paper is an extension of a previous research work in which the mode of operation and performance analysis of each clustering routing protocol is comprehensively presented [3]. The remainder of this paper is organized as follows: In Section 2, investigation of selected clustering routing protocols is carried out. Section 3 summarizes the key features of these protocols and section 4 concludes this paper.

II. CLUSTERING ROUTING PROTOCOLS

In this section, selected clustering routing protocols for wireless sensor networks are surveyed and examined.

A. Low-Energy Adaptive Clustering Hierarchy

The Low-Energy Adaptive Clustering Hierarchy (LEACH) is a self-organizing, adaptive clustering-based routing protocol that minimizes energy dissipation in sensor networks [3], [4]. The fundamental idea behind LEACH is the utilization of randomized rotation of cluster heads so that the high energy dissipation in communicating with the sink is distributed evenly to all sensor nodes in the sensor network [3], [4].

Analysis of Protocol: The dynamic clustering increases the network lifetime. LEACH performs local data aggregation which further reduces energy dissipation and enhances the network lifetime. LEACH protocol faces scalability problems

from large-scale networks. The idea of dynamic clustering brings extra overhead. Periodic data transmissions may drain the limited energy of the sensor nodes. There is the possibility some nodes will not have any cluster heads in their vicinity [3].

Adaptability for Multipurpose Sensor Networking: In LEACH, nodes become cluster members based on the strength of the signal received from the elected cluster heads. This approach can be modified and implemented for multipurpose sensor networking so that different clusters can be tasked with different applications. LEACH employs data aggregation which will ensure that the scarce amount of memory available to the sensor nodes will be efficiently utilized by not overwhelming the sensor nodes with redundant data coming from multiple applications. LEACH uses the cluster head for relaying data. This will reduce energy consumption and ensure load balancing among the sensor nodes that are participating in the multipurpose sensor network. These features are part of the essential criteria for multipurpose sensor networking. However, LEACH does not have fault tolerant capability and the path used for the relaying of data is not the optimal route. This means that the notification to form a cluster for a specific application can easily get lost or the query for a specific data can easily get lost. This is because cluster formation, transmission and reception of data and other operations heavily depend on the network's wireless communication which in turn is not reliable. Therefore, without fault tolerant capability or other reliability measures, LEACH will not be able to perform optimally in a multipurpose sensor network scenario.

B. Threshold-Sensitive Energy-Efficient Sensor Network Protocol

Two hierarchical routing protocols called TEEN (Threshold-Sensitive Energy-Efficient Sensor Network) and APTEEN (Adaptive Periodic Threshold-Sensitive Energy-Efficient Sensor Network) were proposed in [5] and [6] respectively for time-critical applications. TEEN is a protocol designed to be responsive to sudden changes in the sensed attributes such as temperature in the sensor network [3].

Analysis of Protocol: The hard and soft threshold reduces the number of transmissions which leads to energy saving. APTEEN controls energy consumption by using the threshold values and the count time. What limits the ability of both TEEN and APTEEN are the overhead and complexity associated with (1) forming clusters and (2) implementing the threshold-based functions [3].

Adaptability for Multipurpose Sensor Networking: In TEEN, cluster formation is accomplished by grouping nodes which are close to each other. This is a simple technique which can be easily adapted for multipurpose sensor networking. As a result of this, the different clusters will be tasked with monitoring different events. Moreover, aggregation of data coming from multiple nodes is performed by the cluster head. The advantage of this is that the limited memory resources of the sensor nodes will not be wasted by flooding the sensor nodes with multiple but redundant notifications about sensed events. Apart from this, the cluster head is used for relaying data. This will minimize energy consumption and maintain load balancing among the sensor nodes. These functionalities are part of the key criteria for multipurpose sensor networking. However, fault tolerant capability and optimal path routing is not supported in TEEN. The implication of this is that configuration notifications and queries sent in the network can easily get lost. The most likely cause for this is that the wireless communication link is inherently unreliable hence all data transmission and reception will consequently suffer from the same unreliability. Consequently, TEEN will not be able to adapt and operate well without fault tolerant capability or adequate reliability measures in a multipurpose sensor network.

C. Geographic Adaptive Fidelity Protocol

Geographic Adaptive Fidelity (GAF) is an energy-conscious location-based routing protocol [3], [7]. GAF is also a hierarchical protocol where the clusters are associated with the geographic location. The uniqueness of GAF lies in the fact that for each grid area, a representative node acts as a leader to transmit data to other nodes [3], [7].

Analysis of Protocol: GAF conserves energy by identifying equivalent nodes and then turning off unnecessary nodes. The nodes use GPS for positioning which is energy-expensive and costly for sensor networks. The algorithm accounts for travel time for determining the frequent changes in distance which might be difficult to ascertain in sensor networks where nodes are deployed in areas with unfavorable environmental conditions [3].

Adaptability for Multipurpose Sensor Networking: In GAF, each node uses its GPS-aided location to associate with a point in a virtual grid hence nodes that are located in the same grid form a cluster. Apart from the cost of using GPS technology, a modification of this technique can be useful for multipurpose sensor networking. In this case, multiple events will be handled by multiple clusters. Data aggregation is performed in GAF which means that the limited memory resources will be used efficiently. GAF does not use cluster heads for relaying data. This can make it difficult to minimize energy consumption and ensure load balancing among the active nodes in the multipurpose sensor network. Optimal path routing and fault tolerance measures are not provided in GAF. Thus data queries and important notifications used for data collection, network configuration and other operation can easily get lost since they rely on the underlying wireless communication which is unreliable by nature. As a result of this, GAF will not be able to adjust and perform as desired without sufficient fault tolerant capability or any other reliability measures in a multipurpose sensor network environment.

D. Periodic, Event-driven and Query-based Routing Protocol

Periodic, event-driven and query-based (PEQ) routing protocol is designed to meet the demands of sensor networks when they are deployed as surveillance and monitoring applications operating under critical conditions. The fundamental idea behind the PEQ algorithm is simply the use of the hop level of the sensor nodes to minimize data transmission [3], [8].

Analysis of Protocol: The PEQ protocol uses multi-hop communication which is efficient for a large network. The network configuration process ensures shortest path routing and supports low latency. The ACK-based repair mechanism maintains reliability and robustness of the network. A major concern is the redundant flooding and broadcasting of configuration and subscription messages. Network management can be costly and challenging in a scenario where sensor nodes are mobile and numerous [3].

Adaptability for Multipurpose Sensor Networking: PEQ uses a hop tree configuration and a cluster formation algorithm closely similar to LEACH. Hence, this feature can also be modified and adapted for multipurpose sensor networking where multiple clusters can be tasked with monitoring multiple applications. Data aggregation is also supported and used in PEQ which means that the scarce memory resources will be efficiently utilized. However, PEQ does not use cluster heads for relaying data. The negative effect of this is inadequate control of energy consumption and most importantly, load balancing will not be maintained. PEQ has fault tolerant capability and it supports optimal path routing. This means that the important notifications and queries sent in the network are assured to be successfully delivered. This claim is supported by the fact that though data transmission and reception depend on and are prone to suffer from the wireless link which is unreliable by nature, however, with fault tolerant capability, it is expected that PEQ will be able to adapt and perform well for multipurpose sensor networking.

E. Clustering Periodic, Event-driven and Query-based Routing Protocol

The Clustering Periodic, Event-driven and Query-based (CPEQ) protocol is a cluster-based approach in which sensor nodes with more residual energy are selected as cluster heads. The cluster heads form a cluster and the nodes within each cluster send their events to their respective cluster heads. It is the task of the cluster head to compress all these data by an aggregation function before forwarding it to the sink [3], [8].

Analysis of Protocol: The CPEQ protocol has the following benefits; low energy consumption due to multi-hop communication, quick data dissemination via shortest route; support for reliability by the use of ACK-based path repair mechanism. A major concern is the redundant transmission and reception of packets. Network management can be costly and challenging in a scenario where there the sensor nodes are mobile and numerous [3].

Adaptability for Multipurpose Sensor Networking: Just like PEQ, CPEQ's cluster formation approach is very similar to LEACH. Consequently, it is expected that this feature will be useful for the implementation of multipurpose sensor networking where different events are taken care of by different clusters. CPEQ employs data aggregation which will ensure that the limited amount of memory available to the nodes will be effectively utilized for storing important and relevant data. However, cluster heads are not used for relaying data. As a result minimizing energy consumption and load balancing can become difficult to achieve. Fault tolerant capability and optimal path routing is supported and used in CPEQ. This means that subscription notifications, configuration messages and queries are highly likely to be successfully delivered. This is due to the fact that though all network management operations, data transmission and reception are inevitably affected by the unreliable wireless communication link, CPEQ is expected to be able to successfully operate due to its fault tolerant capability in a multipurpose sensor network environment.

F. Energy Efficient Inter-cluster Communication based Routing Protocol

Energy Efficient Inter-cluster Communication based (ICE) algorithm is developed for periodic, event-driven and query-based wireless sensor networks. Routing of messages in the network is done via cluster heads and the nodes closest to each other within two neighboring clusters. Consequently, message propagation through the entire sensor network is accomplished through short transmissions [3], [8].

Analysis of Protocol: The algorithm caters for energy-efficiency, fault tolerance, quality of service (QoS) and network connectivity. It employs data aggregation, reliability, simplicity and quick data dissemination. However, problem arises if the cluster nodes are positioned such that they cannot be projected to the logical line in a cluster. This means that no nearest neighbors will be found and message propagation will be considerably affected. Redundant transmission and reception of packets are bound to occur. Network management can be costly and challenging in a scenario where the sensor nodes are mobile and hugely-dense [3].

Adaptability for Multipurpose Sensor Networking: Just like CPEQ and PEQ, the approach of forming clusters in ICE is similar to LEACH which makes it easily adaptable for application-based network grouping for multipurpose sensor networking. Data aggregation is performed in ICE which ensures that the limited memory resources will be efficiently utilized. However, ICE does not use the cluster head for relaying data. Consequently, it can become difficult to reduce energy consumption and maintain load balancing among the active sensor nodes. ICE has fault tolerant capability and it also supports optimal path routing. This means that data queries, network configuration notifications and other messages sent will be successfully delivered. This claim rests on the fact that though data transmission and reception and other core networking operations heavily rely on the unreliable wireless link which affects these network operations, however, by incorporating fault tolerant capability,

ICE will be able to adapt well and operate optimally for multipurpose sensor networking.

III. SUMMARY OF FEATURES

A summary of the key features of the investigated clustering routing protocols for easy comparison is presented in table 1.

TABLE 1
COMPARISON OF FEATURES

	Mobility	Multi-Hop Routing	Data Aggregation	Multipath	Query-based	Sink Involved in Cluster Formation	Only CH are Relay Nodes	Optimal Route	Fault Tolerance	Multipurpose Sensor Network Ability
LEACH	NO	NO	YES	NO	NO	NO	YES	NO	NO	MEDIUM
TEEN	NO	YES	YES	NO	NO	YES	YES	NO	NO	MEDIUM
APTEEN	NO	YES	YES	NO	NO	YES	YES	NO	NO	MEDIUM
GAF	YES	YES	NO	NO	NO	NO	NO	NO	NO	LOW
PEQ	NO	YES	YES	YES	YES	NO	NO	YES	YES	HIGH
CPEQ	NO	YES	YES	YES	YES	NO	NO	YES	YES	HIGH
ICE	NO	YES	YES	YES	YES	NO	NO	YES	YES	HIGH

IV. CONCLUSION

Routing in wireless sensor networks is still a topic that is attracting the attention of many researchers and it is also posing important research questions. One of such questions is the adaptation of clustering routing protocols for multipurpose sensor networking. Clustering routing protocols ensure that propagation of sensed data to the sink is done with minimum energy. Nodes that are less energy-constrained are tasked with the responsibility of aggregating data and transmitting that data to the sink. In this paper, selected clustering routing protocols for wireless sensor networks are investigated and their features are highlighted. The pioneering routing protocol LEACH is averagely applicable for multipurpose sensor networks due to non-availability of fault tolerant capability and optimal route establishment. TEEN and APTEEN are also moderately adaptable for multipurpose sensor networking due to the lack of fault tolerant ability. In PEQ, CPEQ and ICE, fault tolerance is ensured and optimal route is established. The approach used in PEQ, CPEQ and ICE where the responsibility of message delivery is shared by all nodes in the sensor network achieves load balancing which in turn helps to conserve energy. These make this set of protocols highly adaptable for multipurpose sensor networking. Therefore, Energy-efficient cluster formation, minimization of nodes' database operations (constructing, storing and updating of routing and clustering information), effective data aggregation and fusion techniques, and provisioning for fault tolerance are the key research issues in clustering routing protocols that need further investigation for multipurpose sensor networking.

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