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Obstacle Handling in Context-aware Multilayer Hierarchical Protocol for Wireless Sensor Networks

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Abstract— **Application diversities of Wireless Sensor Networks (WSN) emphasize on consideration of all potential factors including obstacle appearance. However, most reputed protocols of WSN has no or little concerned with this issue. In this paper, simple obstacle detection techniques and their solutions for context aware hierarchical protocols are proposed. These techniques enrich the functionality and deployment ability of the network to a next higher level. Performance evaluation shows effective conjunction of the proposed techniques with the example protocol and durable functionality during obstacle emergence period.**

Keywords-wireless sensor network; hierarchical routing protocol; obstacle handling.

I. INTRODUCTION

Advancement of sensor technology and wireless networking has broadened applications of WSN (Wireless Sensor Network) to a number of diverse fields. Nodes of WSN are getting smaller in size and smarter in sensing, data processing and in communicating wirelessly. However, nodes are ought to be low energy consuming and inexpensive due to nature of major applications [1]. To facilitate such features, a number of energy efficient hierarchical routing protocols have been proposed [2]. Moreover, among these protocols some uses the context awareness aspect for precise cluster formation [3][13][14]. This practice provides distinguishable benefits compare to others.

An obstacle is a common and crucial factor that has been less emphasized in WSN research. An obstacle can emerge as a result of environmental influence, movement of living being or even devastating events. However, most of the prominent protocols of WSN have not considered obstacles as a critical factor. In this paper, we have proposed obstacle handling techniques for context aware hierarchical protocols. We have chosen Context Aware Multilayer Hierarchical Protocol (CAMHP) [5] as an example because of its promising energy efficiency and optimized data traffic. As a part of the techniques, possible obstacle situations have been identified and obstacle detection measures are presented. Obstacle solutions are proposed from a simplistic approach to comply with the nature of sensor nodes and to keep the characteristic of CAMHP intact.

The paper is organized as follows: in the Section 2, key issues of related works are discussed. In Section 3, CAMHP is briefly discussed. In Section 4, eminent obstacle models are reviewed. In Section 5, the obstacle handling techniques are described. In Section 6, performance of the proposition has been evaluated through simulation and proper analysis, and Section 7 concludes the paper with future direction.

II. RELATED WORKS

Research works on obstacle handling in hierarchical protocols of WSN are quite scarce as far as we found. After devoting a handful of time on searching for hierarchical protocol, the focus has been widened to other types of protocol. Among other types, a number of obstacle oriented researches have been found concerned with geographic routing protocol.

In [4], the authors have proposed an obstacle-aware geographic routing protocol which computes obstacle free path through sink. This path information is disseminated towards nodes nearer to the obstacle and formation of virtual circuit is initiated. Temporary destinations on the virtual circuit are used to forward data greedily or by location of destination. Simulation of this protocol shows higher success rate in data delivery and reduction in number of hops. In another work [6], an algorithm is proposed to find the optimal path avoiding obstacle. Based on previous routing decisions, a node's mode (greedy or perimeter) is identified and node reputations are judged accordingly. Then neighbors' reputation-aware nodes choose nodes with good reputation for data forwarding and construct an optimal path. Both of the mentioned routing protocols inherit key constrains of geographic routing such as complicated or costly location information compilation, less or no mobility pre-assumption. Furthermore, in the former, obstacle free path is calculated by the sink which can easily create a bottle neck on the total network. The later one uses planner graph based obstacle avoidance mechanism. However, use of geometric properties incurs high complexity and additional energy consumption.

In an extension of Minimum Energy Communication Network (MECN) protocol [9], authors have proposed

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possible obstacle considerations. Like MECN, the extension Small Minimum Energy Communication Network (SMECN) [10] is self configuring and based on finding a sub-network where communication between nodes consumes less energy. Apart from being a geographic routing protocol, SMECN has some other shortcomings such as finding a sub-network with less number of edges may tally more overhead to the algorithm.

An elaborative and systematic model of obstacles has been proposed in [8]. In a pioneering attempt, authors have defined classifications of obstacle from a simulation perspective. The obstacle model is specified based on different physical and functional properties. Congruent characteristics of the proposed model have been adopted in our proposal. In another proposition [7], obstacles are classified based on their physical characteristics. Both of these classifications are discussed in detail in the next section.

III. PROTOCOL DESCRIPTION

Objectives of CAMHP include achieving maximum energy efficiency as well as wider area coverage. To satisfy such requirements, multilayer hierarchical structure is constructed where basic cluster boundaries are formed based on environmental context. Members of each cluster communicate only with the corresponding cluster head. And, cluster heads communicate with a common super cluster head which communicate with the base station. The network operation is divided into a number of same length rounds. Each of these rounds has two major portions namely setup phase and steady phase. These two phases are described briefly below:

- Setup phase: This phase has three functions: cluster boundary formation, cluster head and super cluster head selection and TDMA schedule dissemination. As the Figure 1 depicts, upon activation in an asynchronous manner, a node senses the environment and decides its role between member node and cluster head role based on the advertised context information if available. If it has same context, it becomes a member node and sends a join message. Absence of any advertisement or for different context, it declares itself as a cluster head by advertising its context information. A member node then checks the number of received cluster head advertisements and their signal strength for a short period. If such number is same as total number of cluster heads in the network (ratio of cluster heads is known as a prior) and received signal strength is strong enough, node identifies itself as a candidate nodes. Such a candidate node then checks its queue for any super cluster head advertisement. In absence of such message, the node declares itself as a super cluster head by broadcasting an advertisement. Otherwise, a node acts as a member node in the following phase. On the other hand, the cluster heads create a TDMA schedule based on join messages. In this schedule, a time span (slot) is allocated for every member node and all slots together forms a frame. Number of frames in a round for a cluster depends on the application. This schedule message also includes a CDMA code which is unique for every cluster and ensures avoidance of inter cluster packet collision. This message is disseminated to the members of corresponding cluster. Thus, all nodes in the network are now aware of their roles. Situation 1: Obstacle between member node and cluster head.
- Steady phase: In their respective slot time, member nodes send sensed data to the cluster head. Cluster head aggregates those data and sends to super cluster head. Upon receiving data from all cluster heads, the super cluster head aggregates and sends the data to the base station.

In the consecutive rounds, a number of performance enhancing measures are initiated. First, data same as previous round are not sent by members. Base station keeps metadata about received data. Thus, whenever packet of a particular node is missing in the current frame, it assumes that data is same as previous frame. This technique reduces the data traffic a great extent. Second, nodes that became cluster head already will not play that role again. So nodes keep a role history of every round. During formation of clusters, member nodes send such history to the cluster head. If a cluster head finds that all of its members have played cluster head role already, it sends an erase flag with the schedule packet. Upon receiving, member nodes erase their role history. This ensures equal energy consumption through the network. Finally, nodes that became super cluster head earlier can play that role again after certain number of rounds. It ensures super cluster head role rotation.

IV. OBSTACLE MODELS

Obstacle models for WSN have been defined in concurrent literatures [4-6] from two different perspectives. In [7], obstacles are categorized into two classes. In the first category, the transparent obstacles, nodes can sense and communicate through them. The real world examples are lake, ponds and swamps. On the contrary, such activities are not possible through opaque obstacles, the second category. In real world, hills, alia, trees and walls resemble such obstacles. Although such classification of obstacles is quite realistic, it is more appropriate for numerical or geometrical analysis of obstacle considerations. There are number of issues such as physical characteristic, stochastic presence needed to be considered for simulation or practical implementation. For precise simulation of real world phenomena, a systematic obstacle model has been proposed in [8]. Obstacles are defined into two classes, namely physical and communication obstacles. Physical obstacle actually prevents presence of sensors. Moreover, the absence of sensor nodes in certain region is also defined as this class of obstacle. Communication obstacles disrupt communication between nodes. Another criterion of obstacle modeling is considering stochastic presence of obstacle. According to such standpoint, deterministic obstacles are considered from the very beginning to the end of the simulation. Whereas, probabilistic obstacles appear in a random time and stays for an uncertain duration. Yet, there is another criterion that takes the obstacle shape into account. Geometric elements are used to describe different type of obstacle shapes such as rectangular, circular, crescent etc. Considering all plausible obstacle models, it can be said that the main trouble obstacles cause is the communication disruption. For other types of obstacles such as for physical obstacle (absence of a node), it has less impact on CAMHP protocol [5]. Because in this protocol node communications are within one hop and member nodes do not depend on each other for data delivery to base station. Moreover, obstacle shapes can be trivial if simple signal propagation models are considered. In other word, distorted, modified or reflected signals can be disregarded as sensor nodes have energy constrained simple communication equipment. According to our consideration, obstacles make a node inaccessible from other nodes. And, presence of such obstacles is non deterministic. So, it is to be considered that the inaccessible node may be functional after certain period of time. This characteristic is important in cyclic cluster formation scheme and we have considered it substantially.

V. Obstacle Handling Techniques

A. *Obstacle Emergence Situations*

Non deterministic obstacles can appear anytime during the two phases of CAMHP protocol. If an obstacle emerges at the beginning of set up phase, then the routing protocol can form clusters considering the obstacle. However, bulk of the time in a round is allocated for the steady phase. In such cases, obstacle situations are detected in the consecutive setup phase. We have identified three possible situations of obstacle emergence. Those situations and their detection techniques are described below:

- Situation 1: Obstacle between member node and cluster head.
  Detection: A member node detects that no advertisement message has been received and according to its own role history it has played the cluster head role already. Thus, this member node has no communication with the cluster head.
- Situation 2: Obstacle between cluster head and super cluster head.
  Detection: Super cluster head detect the communication failure as there is no data form a particular cluster head or from multiple cluster heads.
- Situation 3: Obstacle between super cluster head and base station.
  Detection: As no data form super cluster head has been received, base station detects a link failure.

B. *Obstacle Solutions*

Solutions for above mentioned problems are not identical, rather specific to the situation. Those are mentioned below respectively:

- After detection of situation 1 in steady phase, members initiate obstacle solution procedure in the consecutive setup phase. In the setup phase, if advertisement message is received from a new cluster head, member nodes act in regular fashion. Otherwise, member nodes send join message to the cluster head from which it has received strongest advertisement signal. In worst case scenario, a member node might not receive any advertisement. However, due to communication capacity of nodes and one hop communication strategy, such situation is expected to be rare.
- After detection of situation 2, a super cluster head broadcasts an update beacon at the beginning of the next setup phase. Receiving such beacon, nodes lower the signal strength criteria for becoming a candidate node. Thus, nodes those receive advertisement from all the cluster heads but signal strength is weaker (for example, 50% than previous), now consider themselves as candidate node. As a result, the number of candidate nodes in the current round is increased and from a wider area. Hence, obstacle constrained regions are expected to be avoided.
- Considering the total scenario, situation 3 can create a bottleneck to the network. To avoid such situation, the super cluster head always broadcasts packets destined to base station. This ensures that base station can receive data irrespective of its location on the area boundary. Moreover, an additional base station is added to the system. Multiple base stations are often beneficial to WSN [15]. As both base stations are inter-connected, redundant data is pruned using node id and round number. Figure 6 shows such an addition of a base station to the network.

VI. Performance Evaluation

As far as we know, obstacle handling techniques are not proposed in hierarchical routing protocols. Handling techniques in other types of protocols, for example, in geographic routing are quite different due to differences in basic structure of the protocols. Therefore, we concentrated on activities and topologies of CAMHP for performance evaluation. Obstacle handling solutions in CAMHP had been evaluated using the sensor network extension of J-Sim simulator [12]. This simulator had been chosen for its component based architecture, optimal resource requirement and flexible debugging capability. A simulated environment had been created where sensors sensed temperature of the environment. Obstacle appearances were simulated to create different situations in CAMHP. Obstacle detection and mitigation activities during those situations were carefully monitored and analyzed. For simulating solution for the situation 2, the designated area of CAMHP had been enlarged from 30x30 to 50x50. The designated area [5] is actually the area form where a node can receive all cluster head advertisements. In simulation, this area was rendered in the middle of the scenario.

A. Radio and Network Model

We have used same radio and network model that used to simulate CAMHP protocol. Total 100 symmetric nodes were deployed in a 100x100 area. All nodes had 0.25 unit energy and were set with maximum communication range of 70. The 914 megahertz nodes had maximum bandwidth of 1 megabyte. Energy consumption was calculated using Friss equation [11]. The base was located at (0, 0) location.

B. Obstacle Model

Communication obstacles were imitated in the simulation by making obstacle constrained node inaccessible. Obstacle shapes were not considered as simulated communication equipments cannot process reflected, modified or extreme weak signals. Obstacle's non deterministic behavior had been created by emerging obstacles according to Table 1 during the simulation period.

TABLE I. : OBSTACLE APPEARANCE SCHEMA

Events	Obstacle appearance positions	
	Betⁿ Member & CH	***Betⁿ CH & Super cluster head***
Detection	795th sec.	800th sec.
Sol^{n} activate	805th sec.	805th sec.
Regular operation retrieval	825th sec.	825th sec.

C. Simulation Results

Figure 2 shows a simulation scenario where nodes 1, 2, 4, 7 were cluster heads. Member nodes of cluster head 1 were unable to communicate with it. Conforming the obstacle situation conditions, those member nodes joined the nearest cluster in the next round as shown in Figure 3. At the end of the simulation, energy consumption of the network was recorded as 8.4 units whereas, without such situation, total energy consumption was around 7.4 units for simulation of same duration. In Figure 4, cluster head 32 was unable to communicate with super cluster head 2 due to obstacle. As a result of an update beacon from former super cluster head 2, the designated area had been expanded and node 32 had been selected as a super cluster head from new designated area. This is shown in Figure 5. It can be noted that, the energy consumption was a bit higher (7.9 unit) than obstacle free situation.

D. Analysis and Discussions

Gathering sensed data is one of the main tasks of WSN. Therefore, keeping the communication is our key objective. After appearance of obstacle between member nodes and cluster head as shown in Figure 2, member nodes of this cluster region joined nearest cluster head namely node 39 and 42 in the next round (Figure 3). According to the solution technique, those member nodes worked in a regular mode after the round shown in Figure 3. Although energy consumption is higher than usual, the importance of having data from the constrained region is far more important. Obstacles emergence between cluster head and super cluster head is shown in Figure 4. As a result, obstacle solution was initiated and designated area had been enlarged. New super cluster head (node 34) had been selected from a wider designated area and carried on the communication with the obstacle constrained cluster head (Figure 5). This solution had caused negligible amount of extra energy consumption than usual. Both of these two solutions are completely autonomous and there is no need of central control or extra hardware involvement. Therefore, proposed solutions are worth of enhancement to the CAMHP despite additional energy consumption. As CAMHP do not use any acknowledgement of packets to be energy efficient, it is quite difficult to detect obstacles. Moreover, the solutions are ought to be straightforward to keep the basic characteristics of the protocol intact.

VII. CONCLUSION AND FUTURE WORKS

In this paper, obstacle solutions of an existing protocol (CAMHP) have been proposed. Three core obstacle situations have been identified initially. Then, the protocol has been modified to detect those situations. Moreover, corresponding solutions are appended to enhance the performance of the protocol. Simulations show that the solutions can work efficiently. Despite of some additional energy consumption, the protocol's performance has been enriched by tackling obstacles. Moreover, proposed obstacle handling techniques can be partially or in some cases fully adapted with other hierarchical routing protocols such as LEACH [1], HCR [16], CACH [17]. Future work of this proposal includes a sophisticated technique for obstacle detection for obstacle between super cluster head and base station.

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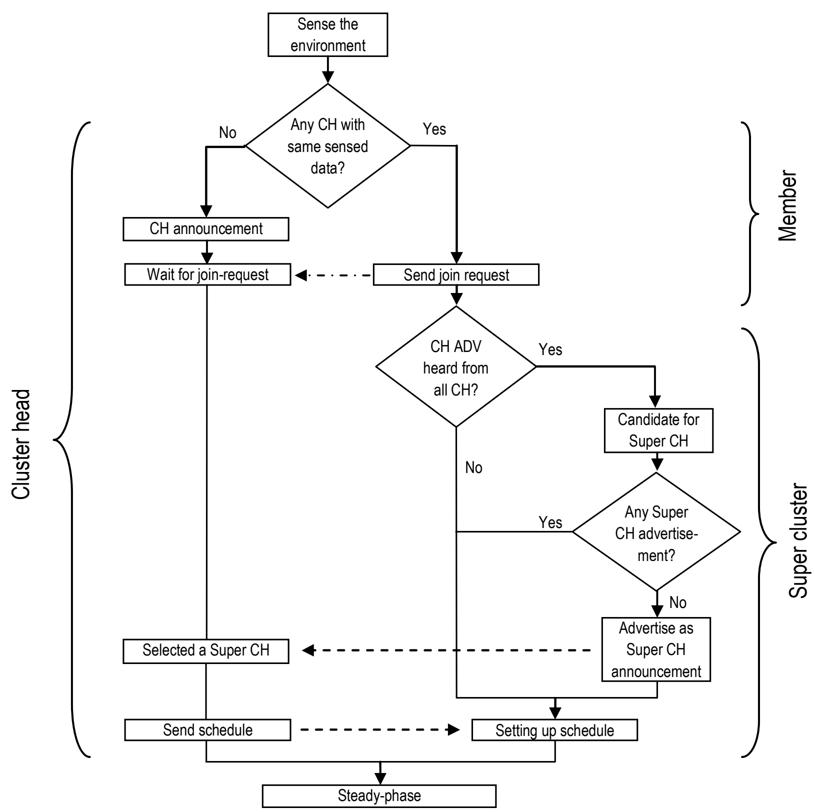

Figure 1. Operation flow chart of CAMHP

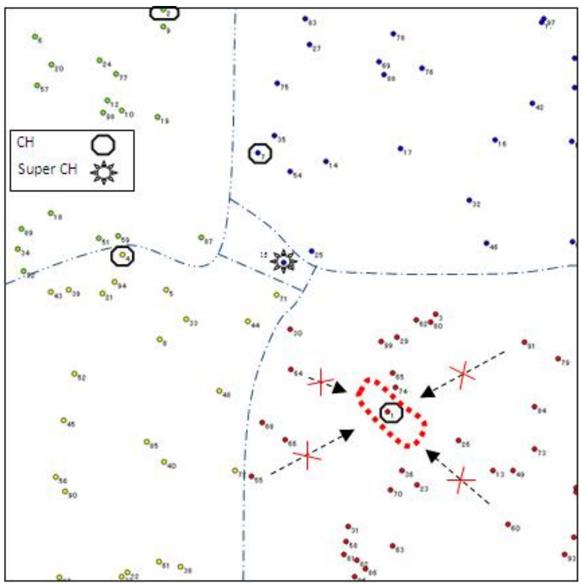

Figure 2. Obstacle appearance between member nodes and cluster head

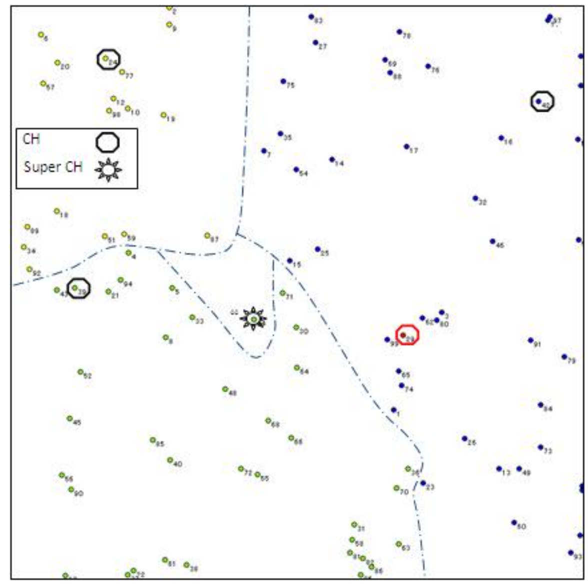

Figure 3. Member nodes joining nearest cluster heads

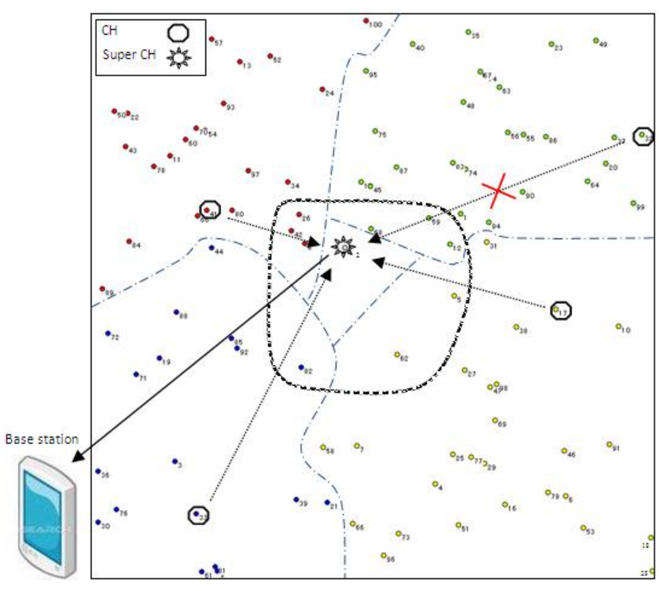

Figure 4. Obstacle appearance between cluster head and super cluster head

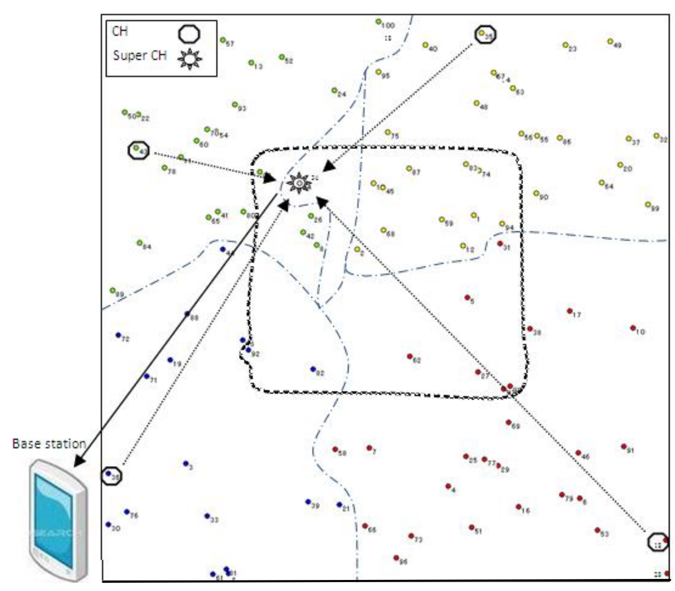

Figure 5. Expansion of designated area

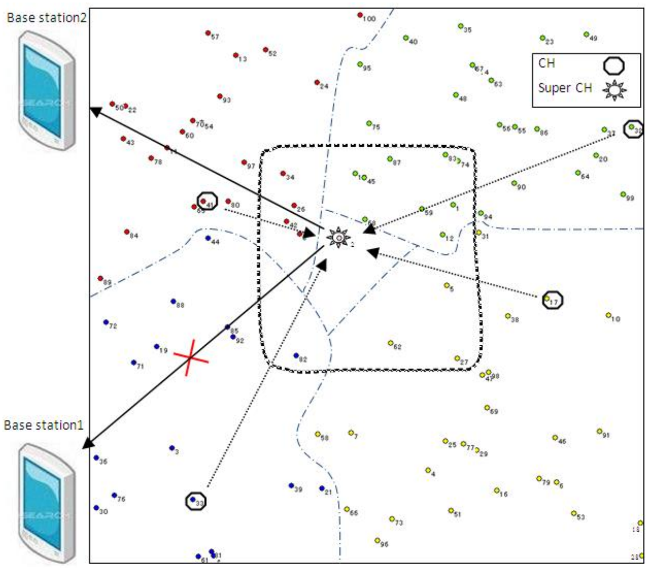

Figure 6. Addition of a base station