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Solving the Hidden and Exposed Terminal problems Using Directional-Antenna Based MAC Protocol for Wireless Sensor Networks

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***Abstract*— A critical design issue for wireless sensor networks (WSNs) is the development of medium access control (MAC) protocols that efficiently reduce power consumption. WSNs sensor nodes are generally powered by batteries which provide a limited amount of energy, and it is often difficult to recharge or replace batteries. Therefore power aware and energy efficient MAC protocols at each layer of the communications are very essential for wireless sensor networks [11]. Fairness to both the usage of a channel and messages may also be traded as for improved power consumptions. In case of classical antennas, unfair channel allocation and wastage of channels between each node can be happened, which is directly affects throughput performance. On the other hand these can bring a problem such as MAC-deadlock, hidden and exposed terminal problem. To overcome these problems a directional antennas have been extensively used in designing MAC protocols for wireless sensor networks. Directional antennas provide many advantages over the classical antennas. *These* advantages include spatial reuse channel and increases in coverage range distance [9]. One of the main considerations in designing MAC protocols for static wireless sensor networks is to reduce power consumption at the sensor nodes. This is usually done by imposing transmission and receiving schedules on the sensor nodes from only one side at same time. Since it is desirable for a sensor network to be self managed, these schedules need to be worked out by individual nodes in a distributed fashion. In this paper, we show that directional antennas can be used effectively to solve a common hidden and exposed terminal problem by using an energy efficient MAC protocol for wireless sensor networks. This directional Antenna could be rotated in case of base station node to avoid directional hidden terminal problem. Our MAC protocol conserves energy at the nodes by calculating a scheduling strategy at individual nodes and by avoiding packet collisions almost completely.**

***Keywords*— wireless sensor networks, Medium Access Control protocol, Energy efficiency, Directional-Antenna.**

I. INTRODUCTION

Due to its various applications in different fields, the Wireless sensor networks are getting high priorities in recent researches. The applications for wireless sensor networks are wide-ranging, usually involving some kind of tracking, controlling or monitoring. Specifically these applications include healthcare applications, fire detection, traffic control, habitat monitoring, object tracking and nuclear reactor control.

To perform these applications, wireless sensor nodes are scattered in a region where it is meant to collect data through their sensor nodes. Such collected information is forwarded to base station; the base station is also sending an updated result to each node. Simple, a sensor node is a node in a wireless sensor network that is a capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network. Each node in a sensor network is typically equipped with a radio transceiver or other wireless communication device and processing unit to communicate to each other or base station. They also contain one or more sensing unit, and power unit.

In this paper we are trying to explore various aspects of medium access control (MAC) protocols in wireless sensor network. The MAC protocols in wireless sensor network must achieve two main goals at minimum [12] [13]. Since, thousands of sensor nodes are densely scattered in a sensor field, the creation of sensor network infrastructure and the establishing communication links for data transfer between them is the first goal of MAC protocol. The second objective is to fairly and efficiently share communication resources between each sensor nodes. As sensors nodes are small size devices they must need less amount of energy. A good sensor network must be fault tolerant, self-organizing and self-configuring, in case of some parts of nodes may fail, so designing such a MAC protocol for wireless sensor network is always an inspirational issue.

The rest of this paper is organized as follows. In the Section II we present theoretically the existing problem with MAC protocols in sensor network. We proposed an optimal solution for medium access control deadlock problems in section III. In section IV we discussed the verification part of our papers which is based on Network Simulator 2 (ns-2) results. The last part of this paper contains the conclusion of the MAC protocol of wireless sensor networks.

II. THEORETICAL ANALYSIS AND PROBLEM DEFINITION IN MAC PROTOCOL

A. SHARED MEDIUM ACCESS PROTOCOLS

A good MAC protocols for the wireless sensor networks must be take care of the following attributes [12]: the well defined energy efficient protocols in order to prolong the network lifetime. These sensor nodes are being a microelectroninic device can only equipped with limited source of a power. The life time of sensor node is directory depending on batter life time. Other important attributes are scalability and adaptability to changes. Changes in node density, network size and topology should be handled rapidly and effectively for a successful adaptation. Some of the reasons at the back of these are network's property changes, limited node lifetime, addition of new nodes to the network and varying interference which may alter the connectivity and hence the network topology. A good quality of MAC protocol should gracefully contain such network changes.

Although, there are various MAC protocols such as Time division multiple access (TDMA), carrier sense multiple access (CSMA), Frequency-division multiple access (FDMA), Wireless Sensor MAC (Wise MAC) and Code division multiple access (CDMA) which have already proposed for sensor networks, there is no protocol accepted as a standard [2] [11] [12] [13] and so designing a MAC protocol is always a challenging research space. One of the main reasons behind this is that MAC protocol choice will, in general, be application-dependent, which means that there will not be *one* standard MAC for sensor networks. Another reason is the lack of standardization at lower layers (physical layer) and the (physical) sensor hardware. Most of these protocols have energy preservation as an objective. The pattern of energy use in the sensor nodes, however, depends on the nature of the application. As the applications of WSNs are large and diverse, the proposed protocols display much diversity.

To avoid co-channel interference among nearby cells, appropriate channel allocation schemes are required to allocate channels to both base stations and access points. If different nodes at same time trying to access the shared channel between them, they cause packet collusions and the packet might be lost. The most common MAC protocols for sensor network are based on CSMA scheme or different. In such scheme the transmitting node first senses the medium to check whether it is idle or busy [8]. The node is following its own transmissions to prevent collations with exiting signal if the medium is not free. To avoid packet collusions problem, another well know solution algorithm was IEEE 802.11. Request-To-Send(RTS)/Clear-To-Send(CTS) exchange resulting in nodes getting exclusive access to the shared channel for a some-defined time period. However, the use of RTS/CTS-like schemes introduces again an unfair channel usage, where some nodes that heard the RTS/CTS exchange refrain from transmission even though they would not have interfered with ongoing transmission [exposed node problem]. Another problem which is unsolved by 802.11 RTS/CTS acknowledgment and handshake packets is hidden terminal problem. Hidden terminal problem is happened due to the two node stations that can't hear the signal sense of each, if they are out of each one ranges. In such cases the interference is caused by the simultaneous transmission of two nodes [12].

MAC-deadlock and others well know channel allocation problem, hidden and exposed terminals are happened in such shared channels. So the performance of wireless sensor network is directly affected with such problems. These problems cause throughputs degradations and unnecessarily wasted of the channels between the nodes. Even though several works have been done to solve these problems, still they are not good enough to solve these problems.

In this paper we proposed a directional antenna MAC protocols that overcome the above problem by receiving/sending the packet only from/to one side at same times. In this case the node could be sense only in the direction of their respective antenna to avoid an energy which is dissipated.

B. PROBLEM DEFINITION

1 Hidden terminal problem

Hidden terminal interference is caused by the simultaneous transmission of two node stations that cannot hear each other, but are both received by the same destination station [1]. Hidden terminal problem is solved using RTS/CTS. We claim that there still exists a problem to the solution

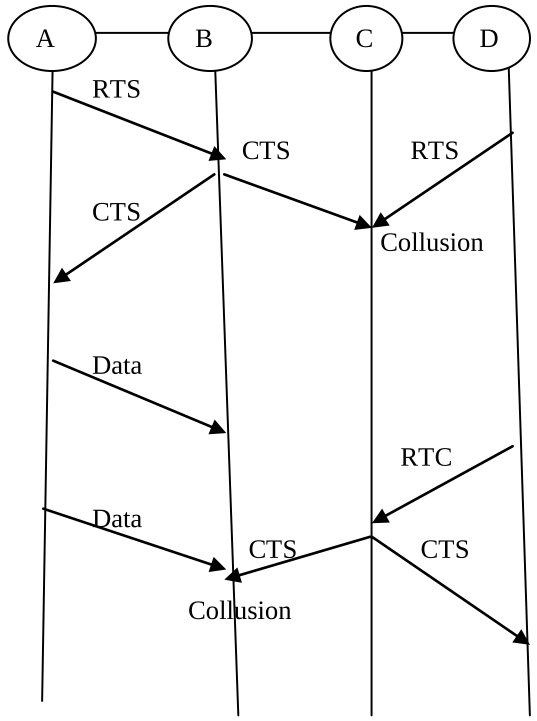

Figure1. Illustration of the situation where RTS/CTS fail to avoid collision resulting in reduced throughput

As depicted in Figure 1, let us assume that there are four sensor nodes A, B, C, D as shown and links between nodes denote their communication ranges. Let us assume that A wants to communicate to B. So, it sends RTS to B and in turn, B broadcasts CTS. At the same time, let us suppose that D transmits RTS to C resulting in a RTSCTS collision at C. Node D timeouts and sends its RTS after the timeout interval. Once C gets RTS from D, it broadcasts CTS. This results in a collision with data from A at B. This occurs due to lack of proper decoding of CTS at C. Thus, RTS/CTS cannot avoid collisions in such a scenario and leads to low system throughput and increased average packet latency. We approach this problem using sensor MAC by using directional antennas so that, all the above problems can be solved with less energy consuming and high throughput..

2 Exposed Terminal problem

The exposed node problem occurs when a node is prevented from sending packets to other nodes due to a neighboring transmitter [12]. Consider the below figure 2, an example of nodes labeled A, B, C, and D, where the two receivers are out of range of each other, yet the two transmitters in the middle are in range of each other. Here, if a transmission between A and B is taking place, node C is prevented from transmitting to D as it concludes after carrier sense that it will interfere with the transmission by its neighbor node B. However note that node D could still receive the transmission of C without interference because it is out of range from B. Therefore, implementing directional antenna at a physical layer in each node could reduce the probability of signal interference, because the signal is propagated in a narrow band.

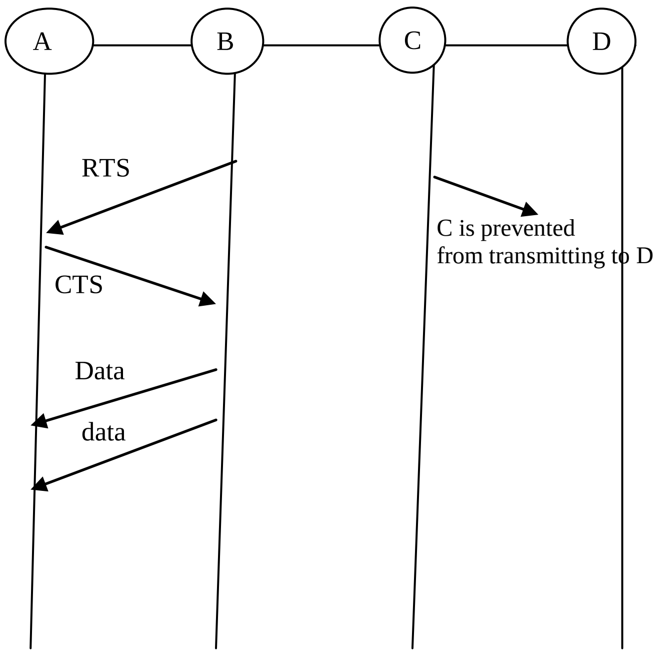

Figure 2: Illustration of the situation where RTS/CTS causes exposed terminal problem

3 Energy related issues during omnidirectional antenna

Accordingly antennas are usually classified by the radiation characteristics into omnidirectional and directional antennas [6]. The most common type of antenna for transmitting and receiving signals at a sensory network is a monopole or omnidirectional antenna. The traditional omnidirectional antennas can propagate the electromagnetic energy of transmission in all around it, i.e., in all directions. Since the transmission range of a signal depends on the power level of transmission, it is usually inefficient to propagate a signal in all direction when there may be only a few intended recipients for a signal [15]. In other words, energy is wasted in propagating a signal in all directions instead of directing the signal towards the intended recipients. The directional antennas focus energy in a particular direction, so that such antenna could consume less energy compared to omnidirectional. The transmission medium is also not allocated appropriately during this omnidirectional antenna, halve of medium access control is unused and it is simple wasted even thought other nearest nodes are waiting to use this medium.

Energy can also be dissipated during packet collisions, which is common problem in such shared channel with omnidirectional antennas [7]. Since the omnidirectional antenna propagates the signal in all direction, this allows the collusion of actual packet with unwanted signal of its nearest node. The signal could also not propagate large distance in this antenna; therefore the propagation delay is high.

III. PROPOSED SOLUTIONS

As we stated earlier, in this paper we contributed a directional based antenna for wireless sensor MAC protocol that conquer the MAC-deadlock, hidden and exposed terminal problem with efficient energy usage. This antenna used with Sensor-MAC protocols so that the antenna is rotated during idle time by hearing its nearest node transmission schedules beams.

However, these directional antenna MAC protocol also present new issues which have not been addressed when using omni-directional antennas. This problem is called directional hidden terminal problem. To avoid this and others related problems, our direction antenna is rotated in an idle state with in some schedule to receive antenna beams from every direction. Whenever it receives antenna beams from its nearest node, the node wake up and starts its communication. The simulation result shows the new protocol is highly improved throughput performance by reducing MAC-deadlock factors, and avoiding packet collusions.

In a directional antennas Gain and directivity are closely related in antennas directions [14]. The directivity of an antenna is an indication of how the Radiofrequency energy is focused in one or two directions at a time. Even though, the amount of Radiofrequency energy is remain the same in both directional and omnidirectional antenna, but in case of directional antenna is distributed over less area, as a result the apparent signal strength is higher and it propagate large distances. This apparent increase in signal strength is the antenna gain. Therefore in directional antennas the interference of a signal is much reduced in both sender and receiver sides

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IV. ANALYSIS OF RESULTS

The problem of hidden and exposed terminal is a common problem in the shared medium access control of wireless network. Hidden terminal arises when two sender nodes out of range of each other transmit packets at the same time, to the same receiver, resulting in collisions at the receiver [1] [12]. Since sender nodes are out of range of each other, they do not detect carrier even though the other node is sending data, and if their data packets reach the destination at the same time, these packets are dropped due to collision at the receiver. In our simulation we have used ns-2 simulator tools. Ns2 is an object-oriented and discrete event simulator designed for networking research, which provides capabilities for simulating WSN. Since our focus is to solve the hidden and exposed terminal problems, this can be clearly shown on graphical user interface (GUI) version of ns-2. A GUI is useful to visualize the simulated network, its virtual cluster formations, and the changes that take place with respect to time.

To show how such problems degrade the throughputs of sensor network as well as dissipate large amount of energy during communication and energy is wasted during sensing in all directions, we have taken various scenarios. In our animation we have taken three nodes, node 0, node 1 and node 2. We assumed that node 1 is a base station for our sensor network. There are other two nodes which are communicating with this base station. Consider the following cases when the hidden terminal problem could be happened in our simulations.

Case 1: When 2 nodes are in range of each other but they do carrier sense at the same time. In this case, since sender nodes do carrier sense at the same time, neither of the nodes is able to detect carrier, hence they both send data packets to the receiver at the same time, thus causing a collision at the receiver. Here we assume data packets reach the destination at the same time [figure 3].

Case 2: When 2 nodes are out of range of each other and they do carrier sense at the same time. Here, since nodes are out of range of each other, they do not detect carrier, and their data packets reach the destination at the same distance, thus causing a collision and hence drop of packets. Here the data packets reached the destination at the same time that caused packets collusion [figure 4].

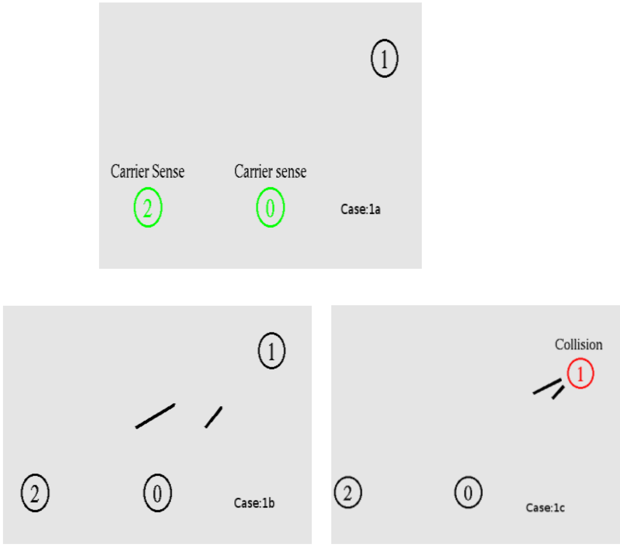

Figure 3: Collision is occurred at the destination. Packets were lost.

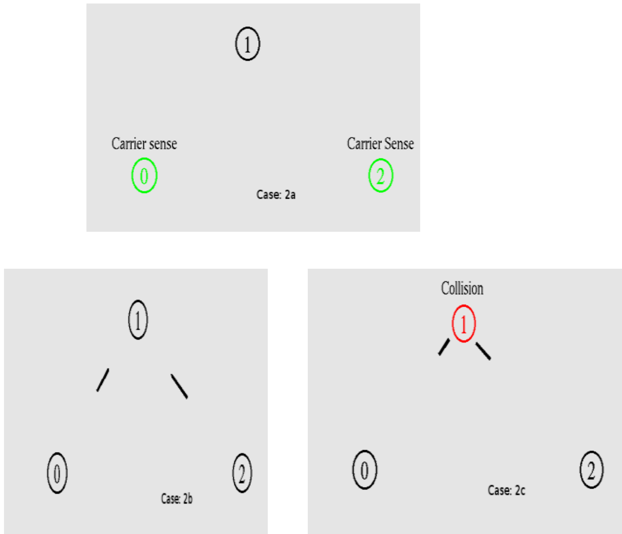

Figure 4: Causing a collision and hence drop of packets.

IEEE 802.11 uses 802.11 RTS/CTS acknowledgment and handshake packets to partly overcome the hidden node problems. RTS/CTS is not a complete solution and may decrease throughput even further, but using directional antenna with Sensor-MAC protocol can produce high throughputs. A highly directional antenna improves the signal reception because it is pointed at the origin of the signal. Multi- and omni-directional antennas pick up all signals from all directions, resulting in too many incoming signals and a weaker signal from the direction of choice. Highly directional antennas also "ignore" signals coming from places other than the one they are directed to, which cuts down the interference with a chosen signal. Another advantage these antennas offer is the ability to change the focus of the receiver to another direction. In point-to-point connection with in a sample small number of nodes in our simulation result, deploying directional antenna at a physical layer has high significant to avoid hidden terminal problem.

As Sensor-MAC offers self-configuration, energy efficiency and flexibility to node changes [10] [11], this directional antenna which rotates its own antenna based protocols, has its own contributions to increase the performance of medium access control protocols as well as to increase the life time of each node. In Sensor-MAC channel allocations we have four major components: The first component is to enables low-duty-cycle operation of nodes in a multi-hop network. So that, the Nodes can be periodically listen and sleep changes the direction of antenna to send and receive the packets, and form virtual clusters based on common sleep schedules. The second component is that Sensor-MAC has adopts contention schemes in sensor node. Third, Sensor-MAC avoids overhearing unnecessary traffic to further save energy. Finally, Sensor-MAC supports efficient transmissions of long messages. Sensor-MAC can also achieve energy savings by minimizing communication overhead, includes the concept of the message passing, in which long messages are divided into frames and sent in a network traffic burst.

V. CONCLUSIONS

In this paper, at first, we have explained the hidden and exposed terminal problem in wireless sensor networks. These problems have an impact on the performance of throughput. We have briefly explained the solution methods. After analyzing the problems, we have proposed the directional antenna based MAC protocol that used with Sensor-MAC Protocol to increase the performance of the output of wireless sensor network. In Directional antenna based MAC protocol since the signals are focus on a narrow beam with large distance the number of multi-hop can be reduced. The directional antennas focus energy in a particular direction, so that unfair channel allocation and wastage of channels between each node can be avoided.

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