A Duty Cycle Directional MAC Protocol for Wireless Sensor Networks

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***Abstract*—The directional transmission and reception of data packets in sensor networks minimize the interference and thereby increase the network throughput, and thus the Directional Sensor Networks (DSN) are getting popularity. However, the use of directional antenna has introduced new problems in designing the medium access control (MAC) protocol in DSNs including the synchonizaiton of antenna direction of a pair of sender-receiver. In this paper, we have developed a duty cycle MAC protocol for DSNs, namely DCD-MAC, that synchronizes each pair of parent-child nodes and schedules their transmissions in such a way that transmission from child nodes minimizes the collision and the nodes are awake only when they have transmission-reception activities. The proposed DCD-MAC is fully distributed and it exploits only localized information to ensure weighted share of the transmission slots among the child nodes. We perform extensive simulations to study the performances of DCD-MAC and the results show that our protocol outperforms a state-of-the-art directional MAC protocol in terms of throughput and network lifetime.**

I. Introduction

Wireless Sensor Networks (WSNs) are getting high priorities and popularities in recent researches due to its emerging applications in many fields including battlefield surveillance, radioactive leakage detection, disaster response, emergency medical care, structural and agricultural field monitoring, etc. These bandwidth intensive network applications are the driving force to explore innovative techniques that can enhance the network capacity. Opposing to WSNs using omnidirectional antennas, a directional sensor node can achieve higher transmission range, reduced interferences and higher data rate, and less energy consumption, etc [1], [2]. Now a days, many applications use directional antennas including multimedia and smart camera sensors [3], [4] in surveillance and target tracking applications[5], precision agriculture applications etc.

Again, an omnidirectional antenna generates interference [6] in all directions that can significantly limit the spatial reusability of the wireless medium [2]. On the other hand, directional antennas can achieve higher spatial reuse by reducing the number of blocked nodes. The directional antennas can concentrate transmission energy in a specific direction and can reduce inter-node interference in a network, increasing the spectrum utilization. Fig. 1 shows four directional nodes in a neighborhood; nodes C and D can communicate to each other while nodes A and B are communicating using the same channel, which is not possible in ominidirectional case. Currently, the availability of low cost computing nodes and the development of new algorithms for processing signals from arrays of simple antennas have made smart directional antennas possible for WSNs [3]. Regrettably, some new problems also come along with the directional antennas including *hidden and exposed terminal*, *deafness* and *asymmetry-in-gain* problems. There are several duty cycle based MAC protocol for WSNs. Nevertheless, the traditional medium access control (MAC) protocols, R-MAC [7], S-MAC [8], B-MAC [9] and Z-MAC [10], etc. designed for ominidirectional WSNs, are not applicable for data communication in DSNs due to their assumption that transmission from a node is overheard by all the surrounding nodes.

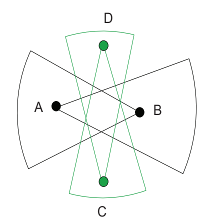

Fig. 1. Directional antennas increase spectrum utilization

In the literature, we find a good number of directional MAC protocols for wireless ad hoc networks [11], [12], [13], [14], [15], [16]. However, the data collection from sensor nodes to the sink in WSNs has some unique characteristics and in wireless environment directional transmission cause some serious problems, thus it is required to design an specialized MAC protocol for directional WSNs. Only a few works [17], [18] address the MAC problem of directional WSNs.

In Sensor-MAC [17], an energy efficient directional MAC protocol is designed for WSNs, in which directional antennas are used effectively to solve the common *hidden and exposed terminal* problems. The Sensor-MAC avoids packet collisions and conserves energy of nodes by scheduling their transmis-

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sions. The key limitation of Sensor-MAC is the consideration of single hop network, where the sink node controls the transmission schedule of all nodes. In DU-MAC [19], idle nodes continuously rotate their receiving beams over 360° for determining single hop neighbors and their schedules, which increases the overhead of the network. The continuous rotations prior to packet transmission for sending the preambles highly increases the energy consumption of the sensor nodes. Furthermore, the DU-MAC does not consider the many-to-one data transmission strategy of DSNs while determining the transmission and reception beams of the nodes, resulting in data loss.

In this paper, we present a novel duty cycle directional MAC protocol for WSNs, called DCD-MAC, that cooperatively determines the transmission and reception schedules of the sensor nodes. The proposed DCD-MAC assumes that the nodes in the network forms a sink-rooted tree, where a parent node may have multiple children and a child has only one parent. It introduces a new data transmission frame structure, which is divided into several slots. Each DCD-MAC parent node cooperatively determines the data transmission slots of its child nodes according to their transmission requirements. Neither the parent nor the child nodes need to continuously rotate the beams; synchronization is carried out at the start of each frame only. Therefore, a sensor node can enter into sleep state whenever it is not scheduled to receive or transmit any data packets. The transmission and reception scheduling of DCD-MAC is fully distributed and exploits local information only; and, thus it is highly scalable. The key contributions of this paper are summarized as follows:

- We have developed a duty cycle Directional MAC protocol, called DCD-MAC, for Directional Sensor Networks.
- A novel data transmission frame has been designed that facilitates synchronized, collision-minimized and energy-efficient transmission and reception of data packets among the nodes.
- The DCD-MAC greatly reduces the *hidden and exposed terminal, deafness* and *conflict of interest* problems (discussed in Section II).
- The DCD-MAC increases the network lifetime significantly by keeping nodes in *sleep* state excepting the durations in which they transmit or receive data or control packets.
- The design of DCD-MAC is based on many-to-one multihop data transmission strategy of sensor networks and thus it achieves higher throughput, higher reliability and reduced data delivery delay.
- Finally, the results of our simulation experiments, carried out in NS-3 [20], depict that the proposed DCD-MAC protocol achieves 49% performance improvement compared to DU-MAC protocol.

The rest of this paper is organized as: Section II describes the challenges of Directional MAC protocol. In Section III, we define the assumptions of MAC design using directional antennas and the system model. The proposed DCD-MAC is introduced in Section IV. The performance analysis and simulation results are presented in Section V, Section VI reviews the related work and concluding remarks and future direction of this research are given in Section VII.

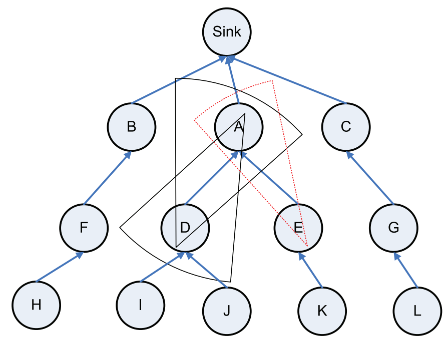


Fig. 2. An example scenario

II. Problem Definition

Compared to omni-directional antennas, the directional antennas allow many multiple concurrent transmissions within the same neighborhood, increasing the network bandwidth utilization. However, the directional transmission and reception introduce additional problems in wireless medium access. Specifically, directional antennas increase the chance of packet collisions because of new type of *hidden terminal*, *deafness*, *asymmetry-in-gain* and *conflict of interest* problems; and, thus they introduce additional challenges in designing high performance MAC protocol for DSNs.

A. Hidden Terminal Problem in DSN

In general, the *hidden terminal problem* is caused by the simultaneous transmissions of two or more nodes that cannot hear each other but they transmit to the same receiver [17]. The problem is more acute in DSNs because a neighbor node may not hear the DRTS/DCTS frame sent by a transmitter if the former is directed to a different direction. This reason of hidden terminal problem is unique in DSNs. Suppose, in Fig. 2, D and E have data to send to node A and D first sends an RTS. Unlike in omnidirectional case, here the node E is not aware of D's transmission and might send the RTS, causing a collision at A. Thus, in DSNs, the collision domain due to hidden terminal problem is increased.

B. Deafness Problem in DSN

In DSNs, *deafness problem* happens when the intended receiver of a sender is beamforming its antenna in a different direction. Suppose in Fig. 2, the parent node A receives packets from its two child nodes D and E using two different beams. While D is sending data packets to A, the node E is unaware about that and it's RTS packet to A will not be responded. If the transmission from D to A or from A to sink prolongates, E experiences many retries and thus it may wrongly regard A as unreachable whenever the retry limit exceeds.

C. Asymmetry-in-gain Problem in DSN

Many existing MAC protocols for directional antennas in the literature use omnidirectional transmissions/receptions for control packets and directional for data packets [12], [21], [11]. It introduces a heterogeneous transmission environment in terms of nodes' transmission ranges and received signal strengths, leading to *asymmetry-in-gain problem* [13]. As a result, all the desired nodes might not be informed about RTS/CTS transmissions of communicating nodes and thus the number of mutually interfering nodes might be increased, degrading the protocol performance.

D. Conflict of Interest in DSN

A major problem in DSNs is to schedule the time at which a parent node collects data from one of its child nodes and for how long it points a particular beam to that child. The *conflict of interest problem* arises when more than one child nodes want to transmit their data packets at the same time. The problem may also appear if the parent itself has data to send to its upper level at that time. Therefore, a good level of synchronization is required among all communicating pairs centered each parent node.

III. Network Model and Assumption

We consider a tree based DSN as in Fig 2. All nodes in a network are homogeneous and share a wireless channel. We also assume that all nodes know their next hop routing path toward the Sink using a static or dynamic routing protocol. A node can either transmit or receive directionally at any given instance of time but can't do both at the same time.

DCD-MAC uses directional antenna for data transmission. For this protocol, we use the switched beam antenna system, which consists of fixed, pre-defined and highly directive beams and each node for each transmission uses only one of the beams.

We assume that each node equips with directional antennas and Fig. 3 shows that an area around the node is covered by M beams. We assume that the beams are not overlapping. In the network, all nodes share a single radio frequency. Both data and control packets are sent and received using this channel. The antenna system of the sink node is omni-directional in our proposed protocol. The antenna systems of all other nodes are assumed to function in directional mode. All nodes in the network must be synchronized with their neighbors in time. This requirement is not difficult to deal with because the nodes can synchronize with each other at the beginning of each data frame slot. The antenna of all nodes function as a switched beam antenna. In the *Sync* phase the antenna of each node would be in directional while transmission and in omnidirectional mode when it is idle and ready to receive any message from it's child. In the *Allocation* phase and *Data Transmission* phase the antenna of each node functions in directional mode.

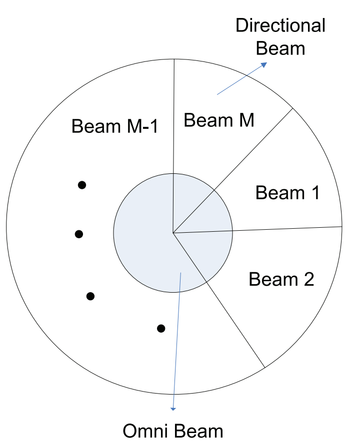


Fig. 3. Antenna Pattern

Sensor nodes in the proposed network periodically alternate between Active state and Sleep state in the duty cycling period. In active state, a node is able to transmit or receive data and in sleep state, the node completely turns off its radio to save energy and hence the network lifetime is prolonged. In this protocol, the data transfer is started according to the previous schedule. The node which is not involved in communication in the *Allocation* and *Data Transfer* phase goes to the sleep state and other communicating nodes remain in the active state.

IV. The DCD-MAC Design

In DCD-MAC, to prevail over the challenges in directional transmission/reception addressed in Section II, we define a new type of frame structure, using which each node can synchronize with other communicating nodes before data transmission and make a schedule of transmissions and receptions in the designated slots of the frame. We also present a collision aware data transfer mechanism for the nodes in their allocated slots. The proposed DCD-MAC introduces a new, low-overhead duty-cycle Directional MAC protocol that allows the nodes to wake up and sleep dynamically depending on their schedules. We describe the detail operation of constituent components of our proposed DCD-MAC protocol for DSNs in the following subsections.

A. The Frame Structure

In DCD-MAC, the time is divided into contiguous frames and each frame is divided into three phases: *Synchronization*, *Allocation* and *Data Transfer*, as shown in Fig. 4. Each of the phases has fixed number of slots: n_1, n_2, and n_3 for *Synchronization*, *Allocation* and *Data Transfer* phases, respectively. Guard time is kept between the slots and the goal of the synchronization and allocation slots is to determine the data transfer slots in which nodes will transmit and receive data packets. In order to minimize the control overhead, the data transfer part is kept much greater than the synchronization and allocation parts; typically, $n_1 = n_2$ and $n_3 >> n_1, n_2$.

In *Synchronization* phase, each node searches for it's neighbors by pointing its antenna in the direction of its neighbors. If connection is established with any of the neighbors, messages are exchanged with each other. Each child node sends transmission request (i.e., the number of packets it wants to

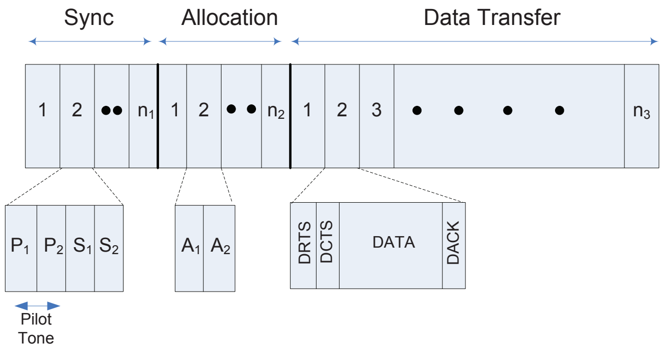


Fig. 4. Frame Structure in DCD-MAC

transmit) to its parent node. The details of the synchronization procedure is discussed in Section IV-B.

In *Allocation* phase, every parent node (including the sink) determines the data slots for each of its child nodes and communicates the allocated slots to its children. Therefore, each node knows its transmission and reception schedules during the data transmission phase. The detailed mechanism of allocation phase is discussed in Section IV-C.

In *Data Transfer* phase, data is transferred from the child to the parent nodes. A parent node moves its antenna beam toward a specific child during the allocated slot and the child node sends its data packets to the parent. The data transfer mechanism among nodes is discussed in details in Section IV-D.

B. Transmitter-Receiver Sychronization

In directional transmission, synchronization of active directions of the nodes before data transmission is very important. Because, without direction synchronization, child and parent nodes will not be directed to each other at the same time for data transmission and reception, respectively.

In the synchronization phase (Sync), each node searches for its neighbors for data communication. In each *Sync* slot, the antenna is pointed to its neighbors one after another. Each *Sync* slot is divided into four sub-slots: P_1, P_2, S_1 and S_2, as shown in Fig. 4. In the first sub-slot P_1, a node transmits a pilot tone to its parent if it has data to send; otherwise, it waits to receive a pilot tone from any of it's children. When a parent receives a pilot tone in P_1, it replies with another pilot tone in P_2 to its child after SIFS time period (as in IEEE 802.11). In idle mode, i.e., when a node is not transmitting it's pilot tone, the node switches it's antenna to omnidirectional mode so that it can hear the transmitted pilot tone from any of it's children. If a parent node does not listen to pilot tones omnidirectionally, then it may happen that, a child node continuously tries to synchronize with it's parent but the antenna of the idle parent node is beamforming towards another direction. As a result, synchronization cannot either occur at all or happen after spending so many pilot tone transfers. Therefore, DCD-MAC nodes receive pilot tones in omnidirectional mode and transmit in directional mode.

After the successful handshaking between the nodes, the nodes exchange the required information in S_1 and S_2 sub-slots. In these sub-slots, the nodes exchange the required number of slots for data transfer and schedule a slot in *Allocation* phase when their antenna can be directed to each other. More explicitly, if any child node sends pilot tone in P_1 to its parent then it will send it's data transfer request information in S_1. In response to this, the parent node will send back the slot number of *Allocation* phase in S_2. The structure of data transfer request message, sent by a child node in S_1 sub-slot, is $< ID, K_1, F >$, where, ID is the node identification, K_1 contains the number of slots it needs to transmit data packets to it's parent and F represents the set of free slots in the *Allocation* phase so that the parent node can determine a slot number in which the child node will be directed to the parent for receiving allocated data transfer slots. After getting this information from a child node, the parent node takes the intersection of it's own free slots and the child's free slots and thus determine the slot number for the *Allocation* phase in which they can direct to each other by using Eq. 1,

$$A_{pc} = A_p \cap A_c \tag{1}$$

where A_p is the set of free slots of parent and A_c is the set of free slots of it's child in the *Allocation* phase. If $|A_{pc}| > 1$, then the first slot of the set A_{pc} can be selected for *Allocation* phase. Thus, each parent node gives the slot number of the *Allocation* phase to it's child nodes so that the child can fix it's beam in that slot to its parent for receiving the scheduled slots during the data transfer.

At the end of the *Synchronization* phase, each parent node will have knowledge about the number of requested data packets for all of it's child nodes. Similarly, the child nodes know the slot number of the *Allocation* phase at which the data transfer slots will be informed by the respective parent nodes. The nodes will finally communicate with each other in the *Data Transfer* phase in their scheduled slots. An example synchronization scenario is depicted in Fig. 5 for the nodes A, D, E, and I, shown in Fig 2.

C. Transmission Slot Allocation

In the *Allocation* phase, each parent node determines the number of data transmission slots to be allocated for each of its child nodes following their requirements collected in *Synchronization* phase. Given that f_i is the number of free spaces in the buffer of a parent node i, it allocates at most f_i number of slots to its child nodes since each slot in the *Data Transfer* phase is corresponding to transmission-reception of one data packet. A DCD-MAC parent node i gives weighted share of the total number slots f_i to each of its n number of child nodes j using Eq. 2,

$$Slots_j = \Big\lfloor \frac{Req_j}{\sum_{j=1}^{n} Req_j} \times f_i \Big\rfloor, \tag{2}$$

where, Req_j is the number of slots requsted by the child node j.

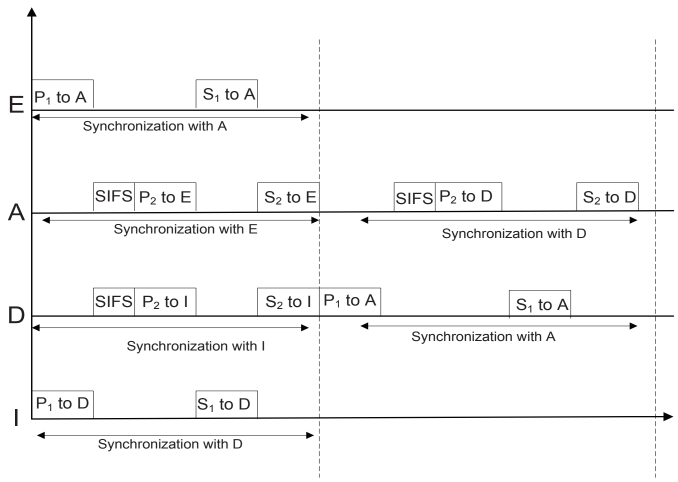


Fig. 5. Transmitter-receiver synchronization mechanism

However, the aforementioned process might lead a *race condition* among the parent-child pairs in allocating the data transmission slots. A *race condition* is corresponding to the simultaneous attempts to multiple parent nodes to allocate the same data transmission slots to their child nodes. For example, in Fig. 2, the parent node D has already allocated slots $\{3,4,5\}$ and $\{6,7\}$ to its child nodes I and J, respectively; however, the parent node A does not know that. In such a case, the parent A might also attempt to allocate the same or overlapping slot numbers to its child nodes, leading a *race condition* for the node D.

A naive solution to this problem is to propagate the slot allocation process from the root of the tree to lower levels so that each parent node is compelled to allocate the free slots only. However, this is quite impractical for large-scale sensor networks due to strict requirement of clock synchronization among the nodes. Moreover, this solution is not scalable. The proposed DCD-MAC gives a distributed solution to the problem by dividing each slot of the *Allocation* phase into two parts: A_1 and A_2. In part A_1, a child node j sends the list of its free slots F_j to a parent node i and in part A_2, the parent node i sends back the list of allocated slots $Alloc_j$, chosen from the slots that are free both at i and j, F_{ij}, computed using Eq. 3.

$$F_{ij} = F_i \cap F_j. \quad (3)$$

Therefore, the slot allocation process of DCD-MAC is fully distributed, exploits local information only and each pair of parent-child nodes are independent from others in allocating data transmission slots. The DCD-MAC parent nodes allocate data transmission slots to their child nodes serially from the list of free slots. This allocation process helps the nodes to increase their *sleep* period as well as to decrease the state transition overheads. Note also that, in the *Allocation* phase, all nodes will be in *sleep* state excepting the slots in which they are scheduled to transmit or receive the data transfer slots.

D. Data Transfer Mechanism

The data communication between two nodes take place in the data transfer phase of the frame. In the particular scheduled slot, the nodes steer their antennas in the direction in which they had planned to communicate with each other. The scheduled packets are then transferred by the child nodes to their parents.

In the DCD-MAC, synchronization between each parent-child pair is done before data transmission and data is sent and received in the pre-scheduled data slots. Therefore, it is guaranteed that transmissions from different child nodes of a parent will not be collided. However, a small possibility of occurring collisions remains among the transmissions from neighboring nodes, if they are directed toward the same receiver. Because, during the synchronization, each parent-child pair checks their own free slots but the data slots of the surrounding neighbor nodes are not checked for the scheduling. Thus, it may happen that two nodes in the same neighborhood attempt to transmit their data at the same time and a collision can occur due to scheduling conflicts.

Our DCD-MAC minimizes the collision among the transmissions from neighboring nodes by introducing Directional Ready to Send (DRTS) and Directional Clear to Send (DCTS) control packets. The exchange of DRTS and DCTS follows the same procedure as RTS and CTS control packets, respectively, used in the IEEE 802.11 standard protocols. It reduces the collision among data transmissions from neihboring nodes.

The DCD-MAC introduces a new low-overhead schedule based protocol that allows the nodes to go to *sleep* state after and before of the operational cycle as stated in Section. III. Let S be the set of all data transmission slots, S_c be the set of slots in which a node communicates with it's child nodes and S_p is the set of slots in which it communicates with the parent, then its duty cycle is calculated as:

$$DutyCycle = \frac{|S_c \cup S_p|}{|S|} \times 100\%. \quad (4)$$

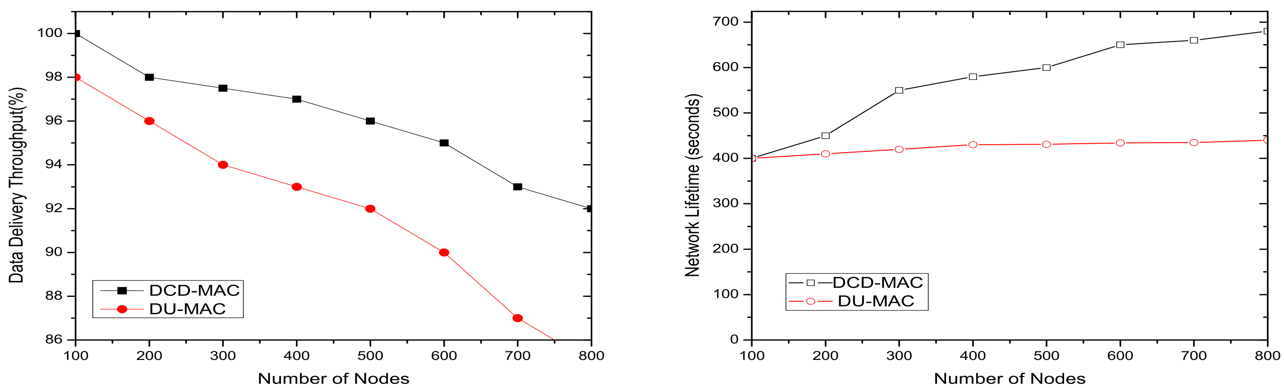
Thus, excepting the *Synchronization* phase, the nodes are allowed to go to low-power *sleep* states during the non-active slots of *Allocation* and *Data Transfer* phases, leading to conserve a significant amount of energy.

V. Performance Evaluation

In this section, we evaluate the performance of our proposed DCD-MAC protocol. In the literature we found many MAC protocols for wireless network which are based on directional antenna but only few of them are focused on Directional Sensor Network. We have done a comparative study between the performances of our proposed DCD-MAC and DU-MAC [19], which also operates in a distributed manner and targets to achieve the same objectives as in DCD-MAC.

A. Simulation Environment

We evaluate the performances of our proposed DCD-MAC protocol in ns-3 [20], a discrete-event network simulator. We use wifiSimpleAdhocGrid model for the simulation. We use



(a) Data Delivery Throughput (b) Network Lifetime

Fig. 6. Impacts on number of sensor nodes

a tree structured network, rooted at the sink, where sensor nodes send data packets toward the sink in multi-hop fashion using a static routing protocol. For calculating the available power at the input of the receiving antenna and at the output of the transmitting antenna, the Friis Propagation Loss Model is used. This model enables fragmentation for large packets. The YansWifiPhy model is used for defining the channel properties such as delay loss, propagation delay, data rate and channel characteristics.

We deploy the sensors uniformly in a region of $1000 \times 1000m^2$. Runtime of the simulation is 1000 seconds. the network configuration parameters are shown in Table I. We take average of 10 simulation runs, with different seed values, for each graph data points.

TABLE I
NETWORK CONFIGURATION PARAMETERS

Parameters	**Value**
Simulation Area	$1000m \times 1000m$
Deployment Type	Uniform random
Number of Sensor Nodes	1000
Number of Sectors	$2 \sim 6$
Transmission Range	$100m$
Sensing Range	$50m$
Initial Energy of a Sensor Node	5 J
Reporting Rate	2 packets per second (pps)
Packet Size	64 Bytes
Network Bandwidth	512Kbps
Routing Protocol	Static
Simulation Time	1000 Seconds

B. Performance Metrics

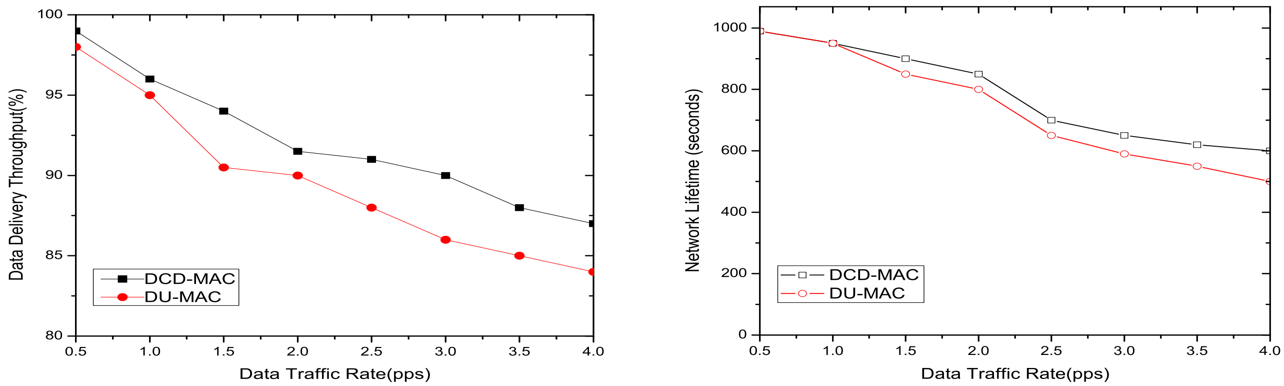
- *Data Delivery Throughput* is measured as the number of data bytes received by the sink per second during the simulation period. The higher the value, better the MAC protocol performance is.
- *Network lifetime* is measured as the time at which the first node of the network dies out of energy. This is a reasonable measurement, used in the literature, since it is expected that the rest of the nodes would also exhaust their energy soon after the first one. Better performance corresponds to the higher amount of time.
- *Protocol operation overhead* is the number of control bytes transmitted per successful data delivery, i.e., it can be measured as the ratio of the number of control bytes transmitted to the number of data packets delivered to the sink during the simulation period.

C. Simulation Results

We examine the behavior of DCD-MAC protocol and compare the results with DU-MAC[19]. To evaluate the robustness of our proposed DCD-MAC mechanism in different environments, we study the performances for varying number of sensor nodes deployed in the network and the data traffic rate. We have calculated the average data delivery throughput, network lifetime and protocol operation overhead for varying number of homogeneous sensor nodes.

1) Impact of number of sensor nodes: The performance metrics discussed before are measured for varying number of directional sensor nodes ranging from 200 to 1000 and the number of sectors is fixed at 4. The graph in Fig 6(a) shows the data delivery throughput with the growing number of sensing nodes in both protocols. In the simulation result we observe that our DCD-MAC has more throughput compared to DU-MAC as it schedules the data transfer before transmitting data. In Fig 6(b) the lifetime of the network in DCD-MAC increases with the growing number of nodes whereas in DU-MAC it remains in a stable state.

2) Impact of data traffic loads: We have calculated the average data delivery throughput and network lifetime for varying data traffic rate. For the simulation we assume that the antenna beam is covered by four sectors and all the data packets are homogeneous. The graph in Fig 7(a) shows that the average data delivery throughput and network lifetime is decreased with the increasing data traffic rate in both protocols because with the growing number of data rate, the buffer of the nodes becomes full soon and also the probability of collision in the network will increase. In the simulation result we observe that our DCD-MAC has more throughput compared to DU-MAC. The graph in Fig 7 (b) shows that, DCD-MAC has



(a) Data Delivery Throughput (b) Network Lifetime

Fig. 7. Impacts on data traffic

more network lifetime in the dense network than DU-MAC.

3) Protocol operation overhead: In Fig 8, we have calculated the protocol operation overhead of our proposed protocol with the studied protocol. The graph in Fig 8(a) shows the protocol overhead for varying number of sensor nodes. The DU-MAC has more overhead than DCD-MAC since active scanning is applied to each individual antenna beam sequentially during the simulation runtime. Again, when the number of sensor nodes is very high, DCD-MAC has less overhead than DU-MAC because in DCD-MAC the synchronization is done only with the parent-child pairs.

In Fig 8(b), we have calculated the protocol operation overhead of our proposed protocol for varying data traffic loads and compared the protocol overhead with the studied protocol. The DU-MAC has more overhead than our proposed DCD-MAC because of the transmission and reception of preamble trailers between the nodes during the simulation runtime. Again, when the number of data traffic becomes very high DCD-MAC has less overhead than DU-MAC because DCD-MAC has a much higher successful data delivery rate.

D. Discussion

The fine performance of the proposed DCD-MAC protocol does not come out of any additional costs. Our in-depth look into the simulation trace file contents reveals that our protocol gives better performance in terms of data delivery ratio and network lifetime. Since the protocol operation overhead of our proposed DCD-MAC much smaller than that of the state of the art work.

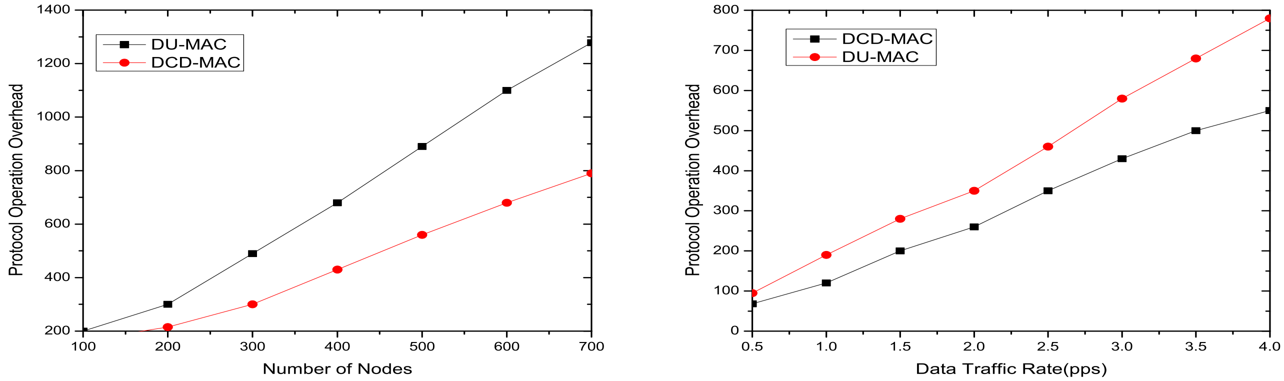
VI. Related Works

Researchers are actively studying the directional transmission technique and designing specific MAC protocols that take advantage of the strengths of this promising technology. When shared channel is used in directional sensor network, many channel allocation problem like hidden station problem, deafness problem can happen. Because of this problems the performance of network is directly affected and cause throughput degradations and unnecessarily wasted of the channels among nodes. Over the last few years several works have been proposed MAC protocol for ad-hoc network but very few works have been proposed for wireless sensor network with directional antennas to solve these problems.

In ad hoc networks random access based MAC protocol design and analysis has attracted extensive research [22], [11], [12], [13], [23]. This existing literature provided us the basis for designing our proposed protocol. A significant number of research efforts focus on adapting the IEEE 802.11 MAC to appropriately work with beamforming antennas. The DMAC [12] is one the earliest protocols that support directional antenna. This protocol is based on a modified 802.11 MAC protocol and uses a persector blocking mechanism to block a sector once it senses a RTS or CTS packet. The protocol requires knowledge of neighbors location. A node can transmit its own RTS packet in an omni-directional fashion when none of its sectors is blocked. For using omni-directional antenna, it cause unnecessary blocking.

Recently, many researches have focused on proposing directional MAC protocols that resolve the beamforming related problems. The majority of the protocols handle the possibility of deafness problems by sending multiple directional control packets sequentially to inform neighbors about the ongoing transmission [24], [25], [26], [27]. Some protocols addressed also the asymmetry-in-gain problem [15], [14]. This approaches reduce deafness but the overhead of these protocols is high enough that limit the benefit of spatial reuse.

In [17], [18], [28] directional MAC protocol is proposed for DSNs. In [17] they first explained the hidden and exposed terminal problems in DSNs and then given an energy efficient MAC protocol by rotating the directional antenna in base station node . This protocol conserves energy at the nodes by calculating a scheduling strategy at individual nodes. But these protocols do not fully exploit the behavior of DSNs and they does not fully handle the new challenges that come along with the directional antenna. None of these protocols introduced the Conflict Of Interest problem which is a very natural problem in DSNs which can happen when scheduling is done before data transmission. A MAC protocol DU-MAC [19] is proposed for UWB-WSN where, the idle nodes in the network continuously rotate their receiving beams over 360 degree till a predefined



(a) Impact on Number of Sensor Nodes

(b) Impact on Data Traffic

Fig. 8. Protocol Operation Overhead

preamble trailer is detected. The protocol deals effectively with the problem of deafness and effectively determine the neighbors' location in the network.

But, in stead of these efforts, there are still remain some difficulties. Some significant problems that arise with the deployment of directional antennas that remain unsolved. Most of the proposed solutions, do not avoid the requirement of omni-directional transmissions and receptions of control packets which results asymmetry-in-gain problem and also limits the frequency re-use capability which can decrease the network throughput.

VII. Conclusion

In this paper, a duty cycle directional MAC protocol, DCD-MAC, is proposed that ensures synchronized transmission-reception between each pair of parent-child nodes. Each parent node in the network cooperatively determines the collision-free data transmission slots for its child nodes according to their transmission requirements. The transmission and reception scheduling of DCD-MAC is fully distributed and it exploits single-hop neighborhood information only. The DCD-MAC is a highly scalable and energy-efficient that allows a sensor node to switch into *sleep* state whenever it is not scheduled to receive or transmit any data packets. Our performance evaluation depicts the effectiveness of DCD-MAC in achieving better throughput and network lifetime. In future, we are planning to perform theoretical analysis in support of guaranteed performances achievable by DCD-MAC. We also study the required changes or modification in the proposed protocol that would help it to achieve better fairness and transmission reliability.

Acknowledgment

This work is supported by a grant for the "Research Fellowship (2013-2014)" funded by the Information and Communication Technology Division, Ministry of Posts, Telecommunications and Information Technology, Government of Bangladesh. Dr. Md. Abdur Razzaque is the corresponding author of this paper.

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