Low Rate WPAN MAC Modification to Suit Multi-Beam Smart Antenna Approach

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Abstract: This research concentrates on exploiting the Multi-Beam Smart Antennas (MBSA) property for the IEEE 802.15.4 MAC Protocol. The MBSA is capable of initiating several data communication by forming spatially separable beams in different directions. With its appealing dimensions, it brings about a new set of challenges. The unique reception and transmission property of MBSA requires an adequate amount of modification to suit the former MAC protocol. We have chosen IEEE 802.15.4 as a platform for our new MAC design with beacon enabled mode, where network coordinator is mounted with MBSA. A coordinator with MBSA boosts up the network performance in the multiple of the number of projected beams. The modified MAC has been simulated using OPNET modeller. The result shows that the performance of the network increases dynamically in terms of delay, throughput and energy consumption.

Keywords: IEEE 802.15.4, Multi-Beam Smart Antennas (MBSA), Multi-Beam Fixed Antenna (MBFA), Multi-Beam Adaptive Array (MBAA), Coordinator (PNC), Slotted CSMA, TDMA.

I. INTRODUCTION

IEEE 802.15.4 MAC protocol is one of the most efficiently used MAC protocol for the low rate Wireless Personal Area Network (WPAN). This protocol has been considered beneficial for the use of Wireless Sensor Network (WSN) also. We assume that our work could be of some use to the sensor networks, because in sensor network we do have huge number of end devices. These end devices are prone to face some urgent situation where they need to transmit some important data to their Sink or say Coordinator. Our concentration is on designing a Multi-Beam Smart Antennas (MBSA) MAC which is bound to perform better than its ancestor because of its multi transmission capability, but it requires precision in its design so that it can benefit us at its fullest. This proposal is beneficial in two aspects. The first is the adaptation of the current superframe based IEEE 802.15.4 protocol with MBSAs in such a manner that it exhibits the similar efficiency as the former. And the other is to handle urgent situations in WSN, where in one geographical area say $\pi r^2 / 4$, there are circumstances when few sensor nodes are sensing some unique changes while others (in $(3*\pi r^2)/ 4$) are noticing the just periodic pattern. These unique and important changes may go unnoticed in the fields where huge numbers of sensor nodes are competing with each other. If the urgent information is not being transmitted at its earliest then the benefits of deploying a huge number of sensor nodes in the field is dubious. The delay caused due to inaccessibility of coordinator node at right time may convert into bigger disaster in a deployment like military warfare, forest fire, flooding, surveillance etc. Therefore, a coordinator node capable of concurrent transmission and reception at its different beam has multiple advantages over a coordinator node with omni directional antenna mode. We have analyzed our work with both kind of MBSAs, Multi-Beam Fixed Antenna (MBFA) and Multi-Beam Adaptive Array (MBAA). Our use of MBSA at coordinator node multiplies the performance of the whole network in terms of energy consumption, delay and throughput. This capacity enhancement is the outcome of better spatial reuse.

This article is further organized as follows: section 2 presents the related studies, section 3 discusses the prerequisite of the MAC design, and section 4 gives the details of MAC design. Simulation and results are the part of section 5, and section 6 concludes the work.

II. RELATED STUDY

We are focusing on the use of MBSA in our work, so at first we gave slight detail of MBSA functioning. The MAC designed for ad hoc network using MBSA is also elaborated and at last we have briefly explained the IEEE 802.15.4 standard which we have opted as platform for our protocol.

A. *Multi-Beam Smart Antenna (MBSA)*

The Multi-Beam Smart Antennas can be categorized into two parts, Multi-beam Fixed Antenna (MBFA) and Multi-beam Adaptive Array Antenna (MBAA). Both of them have been evolved from fixed beam directional antenna and adaptive array antenna.

A fixed beam antenna system consists of several highly directive fixed and predefined beams. These beams are formed to have high sensitivity in particular fixed directions or sectors. In single beam switched directional antenna only one beam is active at a time, concurrent transmissions are not allowed because it has single transceiver. On the other hand, in multi- beam switched antenna there are several beam patterns and each beam is directed to a different user or a sector. Here the numbers of beams are equal to the number of transceivers [1].

An adaptive array is an antenna that controls its own pattern, by means of feedback. It has capability of steering and giving uninterrupted coverage to the end users unlike the fixed beams where we need to switch the beams for continuous coverage to the end users. In case of MBAA the signals from a set of array elements are combined with more than one set of weights to form several simultaneous reception and transmission pattern. We call such an array a Multi-beam adaptive array [15]. Each beam has its maximum response in the direction of the arriving packets and has nulls on the other packets. Such MBAA allows a terminal to receive several packets successfully in each slot. At last we conclude that MBFA and MBAA both have the capability of concurrent reception and transmission where MBSA provides fixed coverage to the end users while MBAA steer their beams as per the need. In MBFA every beam is static in one direction, but MBAA's beam is dynamic and can be steered. Therefore for smooth transmission in the MAC with MBFA, we maintain a table for the location of the end devices on the base of different fixed beam (i.e. sector) of the antenna, while in case of MBAA we keep the track of Angle of Arrival (AoA) of the end devices.

B. Multiple beam MAC protocols

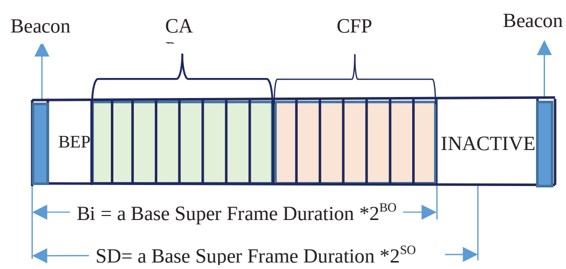
Wireless Ad hoc network research has been given attention to the use of MBSA. One of the first works is by Ward et al [15] in which they have used slotted aloha with multi beam adaptive array. A unique weight vector has been used to identify each packet on different beam of the base station distinctively. Each packet has a preamble of three period of known pseudo noise sequence. They say if packets at different beams arriving with three bit delay the base station will be able to recognize it and that will be a successful transmission. And if a packet is transmitted in same beam from two or more users with less than the above mentioned delay it will collide. Their analysis of the slotted aloha with increasing number of beams shows the better performance in terms of throughput and delay.

Agrawal et al, has some pioneering work [6][7][9][8], which is of great help to the researchers in this field. Their final work introduces a hybrid MAC [6], which is infact their evolutionary effort from previous works, MMAC-NB protocol [7] and the ESIF protocol [8]. It enables concurrent packet reception and transmission at a node equipped with MBSA and is backward compatible with IEEE 802.11 DCF. And it is also extended for the mesh network with heterogeneous antenna technologies and illustrates the advantage over the IEEE standard. In fact their work is based on the WLAN IEEE 802.11 standard, in which they have minutely analyzed the use of MBSA. The challenges and the opportunity has been fairly discussed. The most important thing they devised is the use of appropriate back off scheme when MBSA is applied and how synchronization plays an important role in the whole episode.

Chocklingam [13] has analyzed the performance of slotted aloha while base station is mounted with steerable and fixed multi beam. Their base station is capable of reception of data by steering the beams selectively on the smaller sectors or dividing the neighbourhood into different sectors for fixed beam approach. They observed that under high load condition steerable antenna offers better performance, where as under light traffic static coverage pattern is better. For the detail on the performance analysis of multi-beam approach for the ad hoc network, Amin et al [10][11][12] gives a better insight. Aforementioned approach for the MAC design with MBSA has concentrated only on the wireless ad hoc networks.

C. Overview of IEEE 802.15.4 MAC

The above mentioned standard is approved by IEEE which defines the MAC and PHY layer for low rate personal area networks, and the standard is optimized for low data rate applications [14]. Due to low performance requirements of devices, they may be implemented with very simple and low cost Platforms.



– CAP: Contention Access Period
– CFP: Contention Free Period

– GTS: Guaranteed Time Slot
– BO/SO: Beacon/Superframe Order
– BI: Beacon Interval
– SD: Superframe Duration
– BEP: Beacon Extension Period

Figure 1. Superframe structure of IEEE 802.15.4 [5]

This standard allows the optional use of a superframe structure. The format of the superframe is defined by the coordinator. The superframe is bounded by network beacons sent by the coordinator (see Figure 1) and is divided into 16 equally sized slots. Optionally, the superframe can have an active and an inactive portion. During the inactive portion, the coordinator may enter a low-power mode. The beacon frame is transmitted in the first slot of each superframe. If a coordinator does not wish to use a superframe structure, it will turn off the beacon transmissions. The beacons are used to synchronize the attached devices, to identify the PAN, and to describe the structure of the superframe. Any device wishing to communicate during the contention access period (CAP) between two beacons competes with other devices using a slotted CSMA-CA mechanism. All transactions are completed by the time of the next network beacon. For further detail of working of slotted CSMA and unslotted CSMA for beacon and non beaconed enabled mode of CAP please refer to [14].

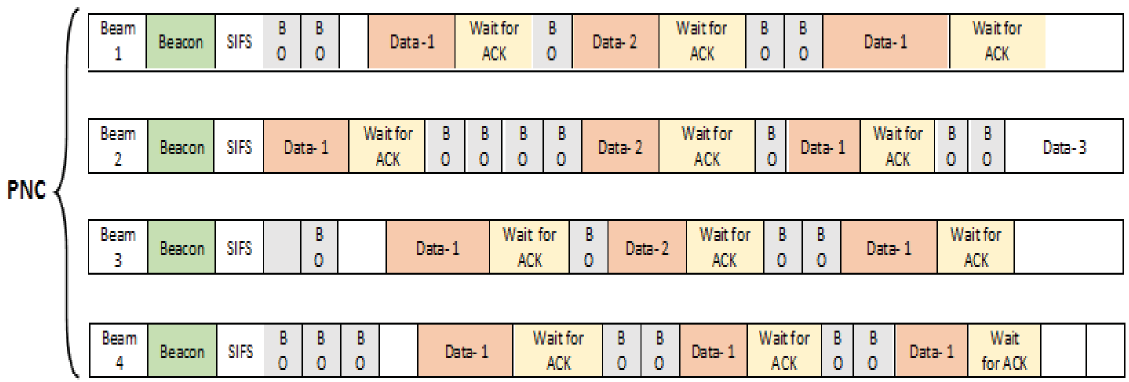


Figure 2. Scenario of mismatch at different beams of the Coordinator

III. PREREQUISITE OF THE MAC DESIGN

A. Multi-beam Smart Antenna Model

We have analyzed our network with both kind of MBSA (discussed in section 2.1) model at the physical layer. Since both (MBFA & MBAA) operate in different manner so their implementation also need a careful attention. Our considered network is a star topology like a cell, with its coordinator node located at its centre. Coordinator node is mounted with multi-beam smart antenna. End users are assumed to be uniformly distributed over the cell area. A slotted channel is shared by all the end devices on the reverse link (End device to Coordinator) for sending data packets to the coordinator. The coordinator receives packet transmissions from the end devices through n, $n \geq 1$, different but spatially separated beams, each having a width of θ radians. The beams are assumed to have idealized, non-overlapping patterns, focusing on perfect 2-dimensional cones of angle θ in given directions on the two dimensional plane. The beamwidth θ is chosen such that $\theta \leq (2\pi/n)$.

For Multi-beam Fixed Antenna

If $\theta = (2\pi/n)$, entire neighbourhood of the coordinator is covered without any hole in the coverage at any given time. Suppose n = 4 (as in our case), it will correspond to a 4 sector scheme with a beamwidth of 90o. This scheme we refer to as the multi-beam fixed antenna approach.

For Multi-beam Adaptive Array Antenna

If $\theta < (2\pi/n)$, In this case, the neighbourhood of the coordinator is partially covered and has holes in its coverage. The angular width of uncovered holes will be $((2\pi/n) - \theta)$. Therefore to achieve the full coverage beams need to steer itself over time, by using array weights [13]. We refer to this scenario as the multi-beam adaptive array scheme. A simple beam steering pattern will periodically shift the direction of beams by an angular amount equal to the beam width θ.

B. Effects of MBSA on IEEE 802.15.4

As we discussed multibeam smart antenna can either transmit or receive at a time but not both. This forces us to rethink the structure of the super frame. Since beacon is required to every one so it need to be transmitted to all the beams to cover the whole neighbour hood.

As specified earlier, different beams can receive or transmit concurrent packet at a time but performing both the task simultaneously is not possible.

In beacon enabled mode of IEEE 802.15.4 MAC superframe is divided into beacon, CAP period, CFP period and inactive period. How the different part of the superframe will react when PNC is mounted with multibeam antenna?

Beacons: Since beacon helped in association and synchronization in the network. Making sure that each end device gets the beacon is very important. In omni mode operation all the devices who are in communication range of PNC receives the beacon smoothly. But we use multibeam approach at coordinator; we need to take extra care about the beacon so that each sector/beam does not leave the vicinity of the PNC uncovered.

CAP Period: This period is the core of the superframe. In omni mode operation, we do not have any multi reception or transmission probability. Even if concurrent transmission takes place through more than one node it results into collision and in turn backoff takes place. The CAP period allows two way transmissions, i.e. uplink and downlink. Most of the data transmission takes place towards PNC in uplink mode but ACK and some specific data request by PNC is served in reversed order. Slotted CSMA/CA approach is only used for data packet not for the ACK transmission. The carefully designed channel sensing scheme maximizes the probability of successful reception of ACK. Now consider the multibeam approach in CAP period and observe the limitations.

Observation 1: After beaconing, each beam allows the end device to start transmission. There is huge possibility that in each beam different end devices requires different no of slots for data transmission. E.g. node A in beam 1 requires 2 slot, node X in beam 2 requires 3 and node G in beam 3 needs 4 slots and so on. This mismatch in the slot request has some impact on multibeam approach we see in further discussion.

Observation 2: Other possible action could be that in one beam/sector the end device x initialized its transmission from 2nd slot while in 2nd beam/sector started the transmission in 4th slot and.

This aforementioned mismatch in observation 1 and 2 causes a puzzling situation for the PNC who wants to switch its one/more beams into transmission mode for the delivery of ACK and requested data, but due to new or little deferred reception at other beams and different random back off taken by different nodes in the different sector of the PNC, it is unable to switch to the transmission mode.

Observation 3: With above discussion it seems that the PNC may be forced to keep itself into reception mode even if it has data and ACK to transmit to the end devices in some beams.

Observation 4: This may go on and on and at last, the end devices that were waiting for the ACK or data packets from PNC will start retransmitting the same data due to unavailability of the ACK, because at some point their maxAckWaitDuration is going to expire. We can say the retransmission by previously finished node will force the whole network in a standstill, because the retransmission with varying number of back off and required slots force the beams to be in reception mode. When retry limit finishes most of the node will go in retrial. This will invalidate the use of multibeam approach for a superframe based IEEE 802.15.4 standard.

CFP Period: CFP period contains different GTS slots, which are assigned to the end devices as per their need. This reservation of slots by different end devices may continue to the several incoming superframes. While reserving GTS, direction of GTS transmission is also reserved. i.e. either uplink or downlink.

Consider the multibeam approach for CFP now. Similar to the CAP period these time slots are also prone to the mismatch in their reservation by the different node in different beam, further more these different sectors's end devices may opt for different direction of transmission. I.e. some may need uplink and some downlink. Furthermore, if GTS is also opted with ACK mode then it makes the situation similar to CAP period where due to unavailability of ACK data starts retransmission. Here situation will not be worse than CAP because at some time GTS slot will be finished but with unacknowledged transmission.

Ultimately, the multibeam approach with the current superframe structure is bound to failure because it faces receiver-blocking problem, and it needs to be reshaped.

In the figure 2 we see that due to different backoff (BO) and different slot required for a data packet in different beam causes the mismatch at different beam, when at one beam reception is finish other beam is still in the process of reception and vice versa.

C. Array Resolution In Beam Forming

One of the most important factors, which may affect the performance of MBAA, while forming a beam, is its angular resolution. Array resolution is important factor in a packet system because if the arrival angles of an interfering packet and the desired packet are too close, the array cannot simultaneously null the interference and form a beam pattern maximum on the desired packet [15]. Therefore, we should be careful in forming the beam pattern in that direction where already some transmission is going on. Therefore, we need to form new beam apart enough from the ongoing transmission with the help of following pseudo code, where we have kept apart different beam patterns on the base of AoA of the new approaching end device.

In the following pseudo-code, the first loop checks the possibility of creation of a beam in some ongoing transmission's direction. According to the condition if new beam pattern overlaps the ongoing beam pattern, then the new beam formation is discarded. Further if above condition assures that there won't be any overlap of the beams then second part works to assign the first free beam towards the approaching end device.

```
/* To check, whether new beam forming is viable or not */
Loop (i = 1, max no. of Beam)
IF (Beam_i is engaged)
Then
IF ((AOA of Approached Beam < AOA of Beam_i + Beam_width) OR (AOA of Approached Beam_i > AOA of Beam_i – Beam_width))
Then
Beam Formation is cancelled
Exit
End IF
End IF
End Loop
/* Pointing the 1st free beam towards the approaching sensor node */
Loop (i = 1, max no. of Beam)
IF (Beam_i is free)
Then
Beam_i = AOA of Approached Beam
Beam Form towards the AOA of Approached Beam
Exit
End IF
End Loop
Print ("no beam is free")
Beam Formation is cancelled
End
```

IV. DETAILS OF MAC DESIGN

Our proposed design of MAC is a modification of the current superframe structure of IEEE 802.15.4 where we have tried to resolve the aforementioned shortcoming of current superframe structure incase of the use of multibeam smart antenna. Figure 3a and 3b shows the two-superframe structure, one for the coordinator node and other for end devices. Network formation process is almost similar to the IEEE 802.1.5.4 standard, but there is no scanning in the beginning for the selection of a coordinator. We have assumed that incase of MBSA approach one coordinator is fixed and end devices cannot make themselves a coordinator.

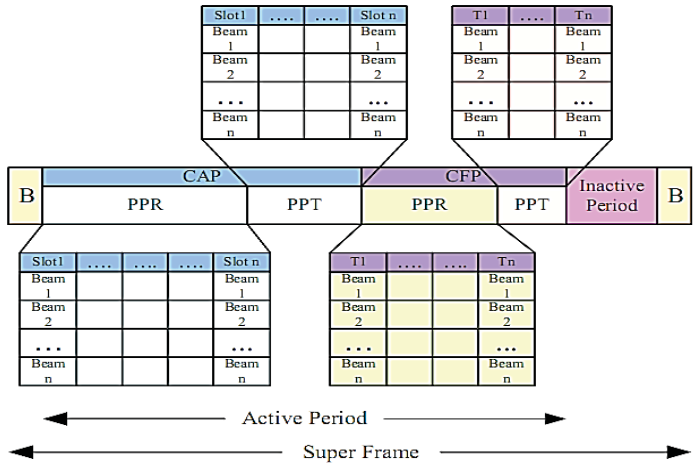


Figure 3a. Superframe Structure for Coordinator Node

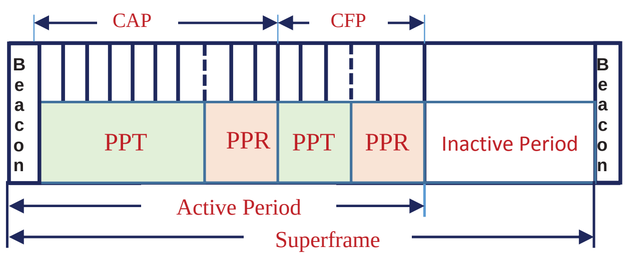


Figure 3b. Superframe Structure for End Device

After channel is assigned to each beam, end devices associates themselves with coordinator to form a star network. The entire approach is similar to the low rate WPAN standard therefore; most of the backend assumptions are similar to that. Coordinator is the one who has the MBSA mounted on it and a unique PAN identifier is assigned to it. Then coordinator goes for the energy detection (ED) scan on each of the sub channels provided in the channel page (in our case 16 sub channels of 2.4 GHz). The ED scan allows a device to obtain a measure of the peak energy in each requested channel and this helps in selecting a sub channel on which to operate prior to starting the network. The energy measured in each sub channels is noted before moving onto the next in the channel list. The top n sub channels that has the highest measured peak energy is assigned to N beams sequentially. The channel as seen by the coordinator node is composed of several sub channels; each sub channel represents a particular beam. Thus, if coordinator node has N switched beams, the total channel throughput is the sum of the throughput over n sub channels [2]. Our protocol operates in the beacon enabled mode therefore in the CAP period (PPR period of Coordinator only) we use the same slotted CSMA/CA approach which is used for IEEE 802.15.4 channel access. It operates in each of the beam independently. The Figure 2a and 2b is the superframe structure of the coordinator and end devices respectively. In both the structure, we have broken the CAP and CFP period into two part named as PPR (Parallel Packet Reception) and PPT (Parallel Packet Transmission) to fix the uplink and downlink mismatch. It should be noted that PPR and PPT periods of coordinator node is opposite to the PPT and PPR period of end device structure. This is to make sure that while coordinator is in receiving mode all end devices are in transmitting mode and vice versa. The above designed structure's use is described here in steps.

Step 1: Coordinator transmits beacon on each of its beam concurrently incase of MBFA, and when we use MBAA, beacon is sent in omni mode for all the end devices.

Step 2: End devices in each beams tries to associate them with coordinator by using scanning strategy of the channels for beacons.

Step 3: Devices, which has data to share with coordinator in the CAP period, they compete for the channel in PPR period of coordinator and PPT period of the device. Channel access using slotted CSMA/CA approach in each sector is allowed for data packets, pending packet request, and GTS slot request. All the transmission in CAP is taken care so that it should not exceed the PPR period of the coordinator.

Step 4: All the required downlink transmission (ACK, Indirect Data) in each of the beam gets chance in the PPT period of the coordinator and PPR period of the end devices. The transmissions, which took place in PPR period with slotted CSMA/CA approach, get acknowledged in PPT period and they do not use carrier sensing. Devices, which transmitted to coordinator, receives the ACK in same order in which they communicated with coordinator. The acknowledgment of pending data request is piggybacked with the data.
Step 5: The CFP period is also divided in PPR and PPT at the coordinator end and it get reversed (PPT and PPR) at the end devices. Here TDMA protocol is used in the reception at coordinator (i.e., PPR) while transmission of ACK and some pending data is also transmitted in PPT period of the coordinator node using TDMA.
Step 6: When CAP and CFP finishes, coordinator and end devices use inactive period to save energy.
Step 7: The entire end devices in the network just wake up to listen the beacon. They listen for the beacon up to superframe duration, if they get it on time they are attached to the coordinator and their synchronization does not require renewal. Otherwise, they go for orphan scanning to catch up with the coordinator again. The scanning procedure is similar to the standard of IEEE 802.15.4.
We fix the time span for either reception or transmission due to the challenge that all the beams of the coordinator can either work into reception mode or transmission mode, not in both at the same time. While transmitting, multibeam spreads its required beams concurrently for packets transmission with strict synchronization and it terminates after the packet duration elapses. But same does not happen in reception, when a node is engaged in reception from one direction, there is possibility that other beam also started receiving some packet from other direction slightly afterward. If this subsequent reception by other beams keeps going, this will turn into a forced reception kind of phenomenon, which will harm the node in terms of its transmission opportunity [2]. Therefore, in our approach we categorized the time period at coordinator as well as end device for the reception and transmission both. When reception time in PPR is not enough for the ongoing transmission MAC does not allow it. Generally this happen when packet size varies and does not match with the slot size of the CSMA/CA.

For successful receptions in CAP (PPR & PPT).

Required Duration in PPR <= Remaining Duration PPR && Required ACK Duration in PPT <= Remaining slot (Duration) PPT

When the network starts, end devices associate themselves with the coordinator. In each sector, coordinator transmits unique beacon frame with the information of PPR and PPT periods. The superframe structure shows that both the CAP period as well as CFP period has been divided into two parts for synchronous reception and transmission. We know that whole superframe structure's duration is dependent upon the superframe order (SO) and beacon frame order (BO). Increase or decrease in CAP and CFP duration is based on the SO and BO. But the new division of CAP and CFP in to PPR and PPT periods poses a challenge. How to divide the CAP and CFP so that every data packet (uplink transmission) can be guaranteed for its acknowledgment (downlink transmission) .For further division of the CAP into PPR and PPT we have utilized the following approach.
When CAP duration is calculated, simultaneously we calculate the duration of PPR and PPT periods. We have assumed that the packet size and ACK size are constant throughout the network in each network formation. Figure 4 shows how this division works.

Step 1. Calculate CAP/CFP duration (slot).

Step 2. Check the Packet & ACK duration (slot).

Step 3. Get the Sum (X) of the Packet and ACK duration.

Step 4. Find the ratio of Packet and ACK duration in the Sum(X).

Step 5. Divide the CAP/CFP duration in the same ratio.

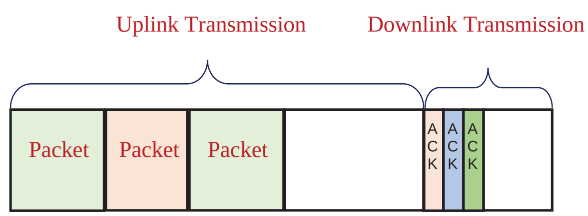


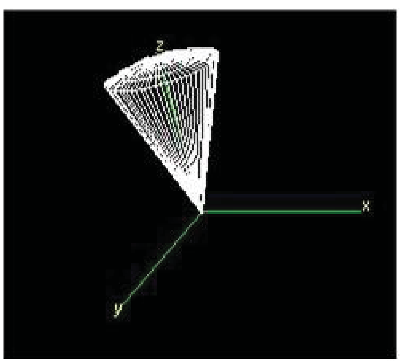
Figure 4. Division of Uplink and Downlink Transmission

The last part of the active period is the GTS, here if the required number of reserved slot is equal in number in each of the sectors/ beam then PPR period of CFP period is same in each sector/beam and there will not be any problem in synchronization. And all the reception in GTS period will terminate at one specified PPR period. But if sector A need 2 slots, sector B needs 3 and similarly other sectors also vary in their required slot, then there will be trouble in reception within specified duration, because if sector A finishes its reception and switches to transmission of ACK. All the remaining reception in other sectors or beams will collapse. For this problem, we fixed the PPR period of GTS at coordinator node equal to maximum number of required slots in any sector/beam. This helps in accommodating every sector's required GTS slot.

V. SIMULATION AND RESULTS

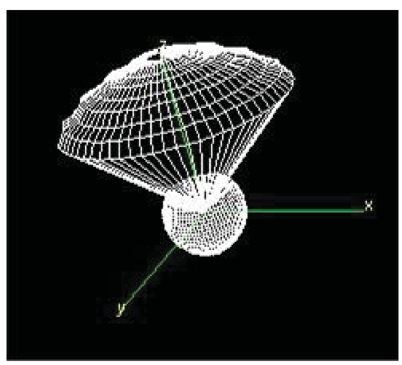
For simulation of this work, we have used OPNET modeller wireless suite to characterize the network performance, used a contributed model, and modified it for the adaptation of MBSA [3], [4]. OPNET facilitates antenna modelling in its antenna pattern editor and it supports the creation of the arbitrary 3D gain patterns. The beam can be pointed at desired point in three dimensions, and the energy received at every node is computed automatically by OPNET kernel procedures. Figure 5a and 5b is the antenna pattern for the MBAA and MBFA respectively. The detailed MAC process design and antenna controller process module is not shown here due to limitation of space. The process model in OPNET is actually a state transition diagram (STD). In the transition diagram, we determine all the actions to be performed. The three important things are associated with STD, the state, events and the condition under which the event occurs. The process model of the MAC of IEEE 802.15.4 has all the states, actions and events required in the protocol such as association, beaconing, CSMA/CA and GTS. In this process model, we add the sector number/AoA as per the used antenna model (MBFA/MBAA) with - received packet according to the receiving antenna and send it to MAC layer and when packet comes from MAC, we check the sector number/ AoA of the destined device and send it to the respective antenna. For instance if sector number is 0 the packet will transmit by using antenna 1, if sector number is 1 it uses antenna 2 and so on.

The performance metrics concerned in this research work are delay, throughput and energy consumptions. The performance has been measured under the following simulation parameter in table 1. We assume beam forming is perfect and there is no beam-overlapping problem in MBFA approach and for MBAA we have devised the algorithm so that any two beams do not overlap. It is also assumed that there is no multipath rich problem. Nodes are evenly distributed in different beam-sectors and most of the traffic goes from end device to the coordinator node. The result has been compared among IEEE 802.15.4 MAC, our MAC proposal with MBFA and MBAA antennas on the base of increasing traffic rate.



Antenna pattern of MBAA

Figure.5 (a) Antennas Pattern of MBAA



Antenna pattern of MBFA

Figure. 5(b) Antennas Pattern of MBFA

Table 1. Simulation Parameter

Network Area	50 * 50 meter
Topology	Star
Min BO Exponent	3
Max no. Backoffs	4
Channel sensing duration	0.1
Directional/Omni	10dB / 0 dB
BO/SO	8/5
Number of nodes	150 CAP Nodes
Coordinator	Mbeam Directional mode
Data Rate	250 kbps
Packet size	512 bits (mean outcome)
Simulation Time	600 Sec

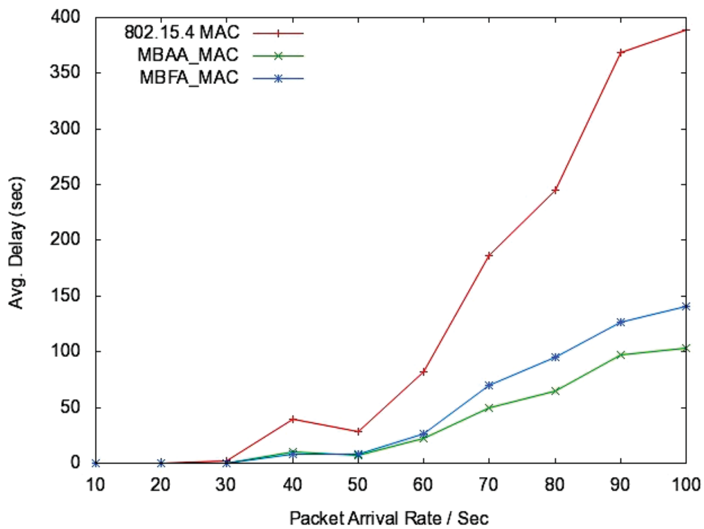


Figure 6. Avg. Delay vs. Packet arrival Rate (Beam = 4)

Figure 6 and 7 represents the average end to end delay of all the packets received by the MACs of all the nodes in the network and forwarded to the higher layer. The MBFA and MBAA performance is better than the IEEE 802.15.4 in both the result because of multi reception and transmission. When offered load is low, MBFA performs better than MBAA but at higher offered load MBAA delay is less.

This is because MBAA get the benefits of spatial separation of the steering beams due to no interference from the end devices in the uncovered neighbourhood. Figure 8 and 9 shows the average throughput of the network. Here throughput is almost multiple of the number of beams. It surpasses the omni mode performance. The throughput of MBAA also outperforms the MBFA due to the reason we mentioned incase of delay. Performance is almost proportional to the number of beams, whatever lack is there is due to synchronization overhead. In addition, the figure 10 shows the energy consumption incase of 4 beams and 2 beams respectively.

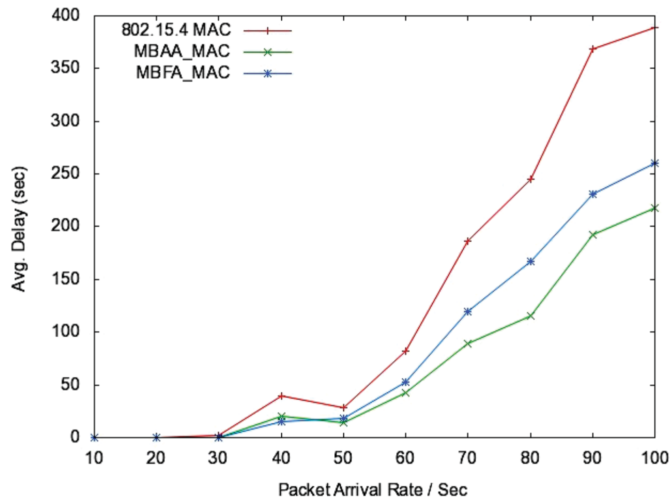


Figure 7. Avg. Delay vs. Packet arrival Rate (Beam = 2)

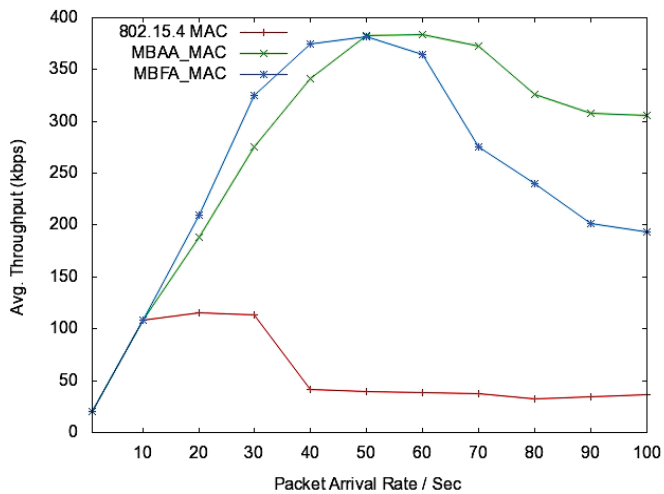


Figure 8. Avg. Throughput vs. Packet arrival Rate (Beam = 4)

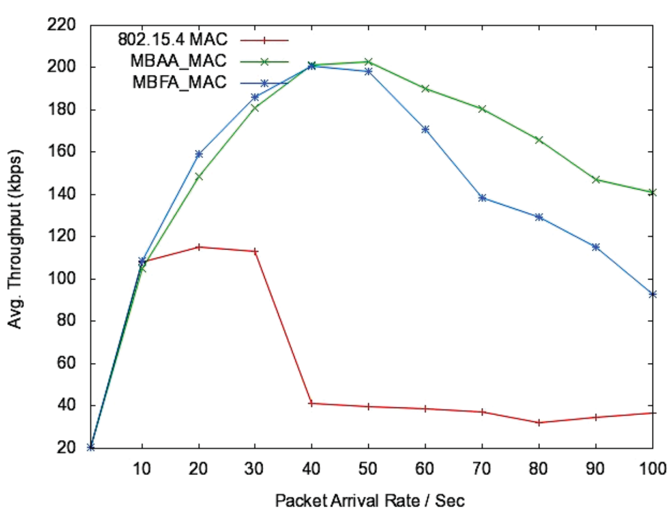


Figure 9. Avg. Throughput vs. Packet arrival Rate (Beam = 2)

Energy is also saved using this approach, although it will raise the burden on the coordinator node.
But in a huge sensor network energy supply to one coordinator to keep other sensors life longer is a trade off which can be tolerated. Due to the sectorization of the neighbourhood end devices, have fewer contenders to compete with so their energy is also saved due to lessened number of retransmission attempt. MBAA with four beams is performing best among all.

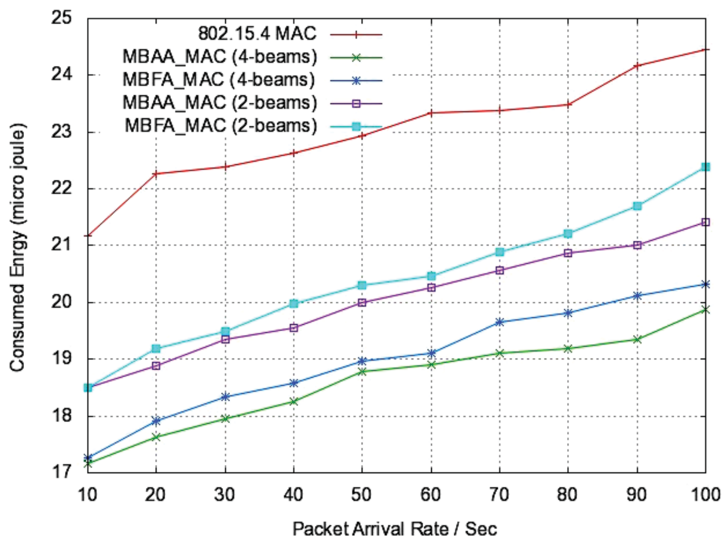


Figure 10. Energy Consumption vs. Packet arrival Rate

VI. CONCLUSIONS

This paper introduces the incorporation of multi beam smart antenna approach for IEEE 802.15.4 MAC protocol. The IEEE 802.15.4 has been taken as the platform, and keeping in mind that the MBSA is constrained to either receive or transmit from its entire beam, but not both at a time, we did certain modifications in the superframe structure of the standard to conciliate our requirements. We gave the details of challenges faced by the standard protocol with MBSA.
The simulation results of the proposed MAC with MBSA are comparatively presented with those of a regular IEEE 802.15.4 omni directional mode. Where we found that due to synchronization and ACK wait duration increment the performance is not in the proportion of number of beams but it is far better than standard. It is also analyzed that MAC with MBAA performs better than the MBFA in higher traffic because of its increased spatiality. Since MBAA has small beam width and it is capable of steering it, it enjoys better spatiality than its counterpart. In the MBFA approach, the beams are fixed and beam width is supposed to be big enough so that it can give full coverage to the neighbourhood without any hole into it. One more cause of its poorer performance is the ambiguity of the end devices on the border of the fixed sectors, in choosing the right beam. Due to this contradictory situation at the end devices, their sensed data is more vulnerable and has lesser chance of successful transmission. By just mounting a multi beam antenna on the coordinator node, we are capable of enhancing the performance.
The multihop and clustering of these small star networks is the task ahead. It will be tedious task to design such a protocol, which can have only coordinator node with multi beam antenna and end devices in omni mode.

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