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Energy efficient and best throughput MAC protocol

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ABSTRACT: "Smart Cities" has been envisioned during the last decay. Moreover, various projects have been initiated to bring this concept into reality. Smart City is basically an emergence of the existing and new ICT technologies to make our living standard more safe and digitized. Wireless communications such as sensors, actuators, intelligent transportation systems, smart grids have played a vital role in the dissemination of information under the given circumstances. Similarly, it is hard to declare any "city" as a "smart" without taking benefits from Wireless Sensor Networks (WSN). However, with new requirements, and delay sensitive applications, the existing WSN requires significant alterations at several layers. In this paper, a new TDMA based MAC protocol, called Energy efficient and Best throughput MAC (EEBTMAC) is proposed for adaptive traffic in hierarchical Wireless Sensor Networks (WSNs) that can be deployed in the smart cities. EEBTMAC is specifically designed to improve the quality control of such smart cities applications where diverse traffic is required and loss or delay in data traffic is unacceptable. The main contribution of EEBTMAC is that: (a) it uses small size time slots. (b) the number of those time slots are more than the number of member nodes. (c) Knapsack algorithm is used to schedule time slots. (d) Short node address (1 Byte) is proposed to identify member nodes. First two contributions of (EEBTMAC) handle adaptive traffic loads of all members in an efficient manner. The knapsack algorithm not only reduces the job completion time of a node but also minimizes the average packet delay with better link utilization. The short node address reduces the control overhead that improves the energy efficiency. The simulation results verify that the proposed EEBTMAC transmits more data with less delay and energy consumption compared to the existing MAC protocols.

Index Terms: Smart Cities, Wireless Sensor Networks, MAC, TDMA, Contention Free.

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I. INTRODUCTION

According to the UN habitat survey [1] conducted in 2008, more than 50% global population lives in urban cities and it is predicted to be 70% by 2050. In smart cities, there are more number of nodes than human population. These nodes are deployed to gather variant data for multiple smart city applications. Due to dramatically decrease in cost of simple and complex sensors, capturing of data is preferred by deploying wireless sensors. To improve the impact of urban quality of life and to maintain the quality of services of smart cities applications, online data with accuracy and without any unnecessary delay is required. In addition to its multiple advantages, there are some challenges being faced in terms of energy limitation, delay, scalability, throughput and control overheads. Many researchers have tried to address some of these constraints by introducing different Medium Access Control (MAC) protocols. MAC protocols for wireless networks are basically divided into two main categories: (a) Contention based and (b) Contention free or Scheduling based [2].In contention based MAC protocols, data sending node (Source node) contends to access the medium. If medium is found idle then node transmit its data. When there are more than one source node try to access the medium at the same time, then there are chances of collisions. Due to collision, each node has to resend its data. This, not only cause delay in data delivery but also depletes the wireless nodes early. This problem rises in a densely deployed wireless network. IEEE

802.11 [3] is a well known contention based MAC standard, specifically designed for wireless networks. This standard is designed for high data rate with high processing applications and is not suitable for low data rate and low processing applications such as WSNs. That is why this standard is not recommended for WSN. Some of the well known contention based MAC protocols for WSN are Sensor MAC (SMAC) [5], Time-out MAC (TMAC) [6], Berkeley MAC (BMAC) and Utilization based duty cycle tuning MAC (UMAC) [7]. In most of the smart cities applications, delay or loss of data cannot be compromised, therefore, contention based MAC protocols are not suitable in such scenarios.

In scheduling based MAC protocols, chances of collisions are avoided by assigning separate time slot to each source node. One of the most common scheduling based MAC protocol is Time Division Multiple Access (TDMA). In TDMA, each node is allocated a Guaranteed Time Slot (GTS) to access the medium. In this protocol, collisions are avoided, however, energy consumption during idle state is not avoided as node keeps its radio ON during its allocated GTS even if it has no data to send. This limitation was addressed in Energy efficient TDMA (E-TDMA) [8]. E-TDMA is proposed for hierarchical networks, where whole network is divided into small clusters. In each cluster, a Cluster Head (CH) is elected and all member nodes of that cluster transmit their data to their CH by following E-TDMA. In E-TDMA, a member node keeps its radio OFF, when it has no data to send during its allocated GTS.

TDMA and E-TDMA save energy loss by avoiding collision however, due to limited number of data slots, they are non productive in scalable environment. Another constraint of both of these protocols is, they are unable to handle adaptive data traffic.

Varying data traffic in a WSN does not allow all nodes in a network to transmit same amount of data. Due to different transmission behavior, It has been observed that different transmission behavior causes nodes assigning same tasks hav- ing different transmitting and collecting time. To overcome this problem, TDMA based MAC protocols have been moderated, such as, Bit-Map-Assisted (BMA) [16] and Bit-Map-Assisted with Round Robin (BMA-RR) [17]. BMA addresses unused slots of nodes and assign these slots to more data requesting nodes. In BMA, fairness is not considered, which has been addresses in BMA-RR by allocating unused data slots to more data demanding nodes by applying Round Robin technique.

These techniques overcome some of the limitations of TDMA and E-TDMA at the cost of increased control over- heads. Also, they do not address scalability issues. Both of these techniques offer fixed number of data slots, which are unable to handle adaptive traffic load efficiently. In result, delay and throughput is not optimized effectively.

In this paper, we propose Bit map assisted Efficient Scalable
TDMA based MAC protocols (EEBTMAC), that:

1) Considers large number of small size time slots and these time slots are not equal to number of member nodes. This will help in handling adaptive traffic needs in an efficient manner with increase in Link Utilization.
2) Knapsack algorithm is applied not only to reduce node's job completion time but also to allow more nodes to transfer their data within available time slots. In addition to reduce the average packet delay of the network, it also increases the link utilization of the network.
3) A separate Contention access period is introduced in the proposed architecture to accommodate non-member nodes to become a member of the network during data transferring phase.
4) Overheads are reduced by allocating each node a short address of 1 Byte instead of 8 Bytes extended address.
5) Proposed scheme can accommodate 255 wireless nodes in a single cluster.

Rest of the paper is organized as follows: Section II discusses the previous work related to the proposed scheme. The pro- posed TDMA based MAC protocol is described in Section III. Section IV evaluates and compares the performance of the proposed EEBTMAC protocol with the existing ones. Finally, Section V concludes the paper.

II. RELATED WORK

Increase in life cycle of a WSN is one of the main objective, that can be obtained by avoiding unnecessary energy consumption of a wireless node. Scheduling based MAC

Protocols are preferred over contention based MAC protocols as energy wastage due to collision is avoided. Previously proposed TDMA based contention free MAC protocols are going to be briefly discussed in this section.

S-TDMA [9] is a TDMA based MAC protocol designed for wireless sensors. In S-TDMA, authors address those TDMA features causing un-necessary energy loss by keeping nodes in sleep mode when do not have any data to transmit. Latency has also been minimized by eliminating those empty slots, where nodes have no data to transmit. Delay Guaranteed Routing and MAC (DGRAM) [10] is proposed for such applications, where, delay beyond certain limit is un-acceptable. This objective is achieved by re-using the allocated time slots. In [11], CSMA and TDMA based Intelligent Hybrid MAC (IH-MAC) is proposed. Main objective of IH-MAC is broadcasting and link scheduling. The protocol reduces the delay by intelligently utilizing the strengths of both CSMA and TDMA. Energy consumption is reduced by varying the transmitting power of a wireless node. In [12], Traffic Pattern Oblivious (TPO) is proposed that is a scheduling based MAC protocol. Unlike TDMA, TPO is capable of collecting data continuously on the basis of dynamic traffic pattern efficiently. It allows gateway to gather data traffic on the basis of traffic load. In [13], a TDMA based MAC protocol is proposed and its performance in terms of link quality estimation is evaluated by implementing it in CC2530 hardware and tested it in industrial field.

In [14], energy efficient TDMA (EA-TDMA) is proposed. EA-TDM is specifically designed for communication between wireless nodes deployed in railway wagons.

Most of these TDMA based MAC protocols target energy

Consumption or unused time slots. Similarly, we previously proposed a BS-MAC [15] protocol that was originally de- signed for adaptive data traffic for WSN. However, BS-MAC along with other previously proposed TDMA based MAC hardly entertain scalability issue for WSN in smart cities, especially when the new arriving nodes cannot be accommodated during certain SSP. Whereas, in EEBTMAC, scalability constraints have been covered by introducing CAP which allows other nodes to join the network during SSP. In addition, energy efficiency has been improved by reducing the control overheads and Knapsack optimization scheme along with reduced data slots are used to improve the link utilization and end to end delay of the network. More details about BEST- MAC are discussed in the next section.

III. PROPOSED EEBTMAC PROTOCOL

This section describes the proposed TDMA based MAC pro- tocol, called Bitmap-assisted Efficient Scalable MAC (BEST- MAC), for cluster based or hierarchical communication scenarios. Multiple clustering techniques have been proposed in WSNs for competent routing between wireless nodes and sink [18]. A WSN is mostly divided into many groups and each group is called cluster. One of the nodes in each cluster is elected as a CH and rest of the nodes in that cluster act as member nodes. All the member nodes transmit their data to its CH. Each

CH is responsible to transmit all its collected data to sink. All nodes in a cluster before the start of a new round elect a CH on the basis of stochastic algorithm [19]. Communication round starts immediately after the successful selection of a CH. Each communication round consists of a Setup Phase (SP) and Steady State Phase (SSP). SSP is further split into multiple Sessions and each session comprises of a control period, data slot announcement period Contention Access Period (CAP) and data slots. A complete communication round is shown in Fig.1.

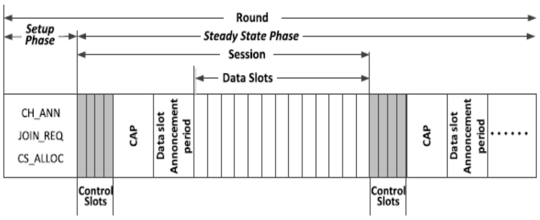


Fig. 1. One round of a cluster in EEBTMAC

A. Setup Phase (SP)

A communication round starts with SP. Following steps take place during SP.

1) Elected CH broadcasts announcement message (CH_ANN) message. CH_ANN is a 10 Bytes frame and segregated into control portion (1 Byte), CH’s extended address (8 Bytes), broadcast address (1 Byte) and Frame Check Sequence (2 Bytes).

2) Those nodes who want to become member of that cluster, responds with the Join Request (JOIN_REQ) messages upon receiving advertisement message. Before transmitting (JOIN_REQ) messages, nodes need to con- firm the medium availability by performing CSMA/CA operation. The JOIN_REQ message comprises of 19 bytes. This includes 1 byte Control portion, 8 bytes each for Node’s and CH’s extended address and 2 bytes for FCS.

3) CH waits for a specific time to make sure that, all the JOIN_REQ messages have been received successfully.

4) CH calculates the total number of member nodes by counting the received JOIN_REQs.

5) CH assigns a unique short address of 1 Byte to all its associated nodes by declaring as member nodes. CH also allocates one of the short address for itself. Therefore, maximum 255 nodes can be associated with a CH.

6) CH allocates control slot to each of its member node and this information is broadcasted to all its member nodes through CS_ALLOC message, as shown in Fig.2. CS_ALLOC message comprises of a control byte, CH’s extended and short address, node$_i$’s extended and short address, node$_i$ ’s allocated Control Slot number, Control Slot Duration (CSD), Total number of control slots (TOT_CS), s_i , Start Time of Data Slot Announcement Period and FCS. CS_ALLOC message length mainly depends upon the number of member nodes. The al- location of short address helps in reducing the control

Overheads during all sessions of a SSP. It is mandatory for all member nodes to listen CS_ALLOC messages not only to get information about their assigned control slots but also to know about the end of setup phase and start of control slots. In case, some member nodes do not receive

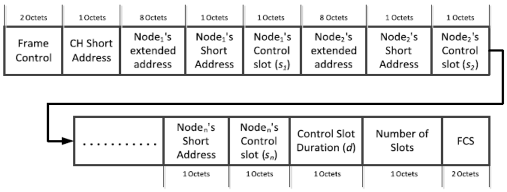


Fig. 2. CS_ALLOC Message Format.

CS_ALLOC message, they are no more in that cluster range and have not become part of the network. However, these nodes may request to become member of that network during CAP of SSP. The detailed flow diagram of Setup Phase is shown in Fig. 3.

Each node computes its allocated control slot by 1 E.g, if a member node has been assigned control slot number 'C' then beginning of its control slot (CS_Start) is computed as:

$$CS\_Start = CSD \times (C - 1) \quad (1)$$

Each member node must requires to listen CH's Allocated Data Slot Announcement (ADS_ANN) message. In our pro- posed MAC architecture, ADS_ANN message commences after Control Period (CP) and Contention Access Period (CAP), which can be computed by each member node as:

$$ADS\_ANN = CP + CAP \quad (2)$$

Here $CP = TOT\_CS \times CSD$ and $CAP = 256 \times CSD$

$$ADS\_ANN = (TOT\_CS + 256) \times CSD \quad (3)$$

B. Steady State Phase (SSP)

After successful completion of the SP, Steady State Phase starts immediately. SSP consists of multiple sessions which starts with CP and then followed by CAP, ADS_ANN message and data slots respectively.

1) Control Period (CP): All data sending nodes are required to send data request during their allocated control slots whereas, nodes, having no data request keep their radios off to save their energy. However, coordinator remains in idle listening mode during whole control period. This control frame contains of 48 bits. Each control frame comprises of following information.

1) Control frame pattern (4 bits).
2) Short message of data requesting node and coordinator (16 bits).
3) Number of data slots required to send data (12 bits).This means maximum capacity of transmitting data by a source node in BEST_MAC is 24576 bytes.

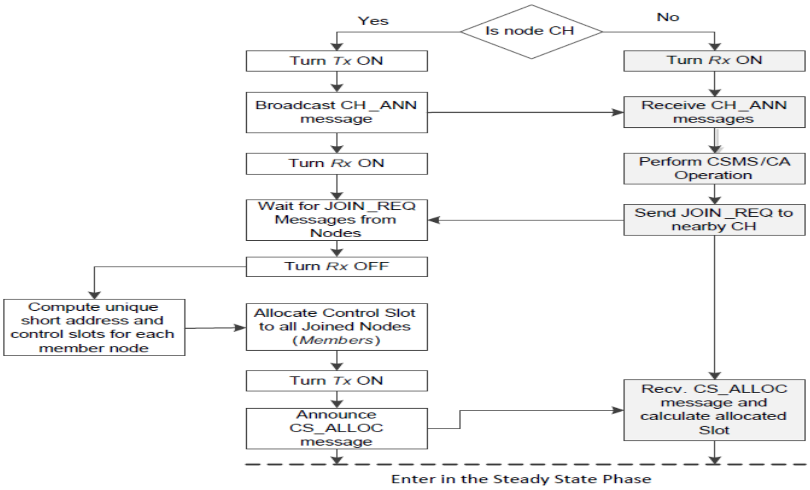


Fig. 3. Communication between a CH and Member Node during Setup Phase

4) Frame check sequence (16 bits).

In BEST_MAC, each data slot is a simple multiple of CSD. Each node computes its Required Number of Data Slots (REQ_DS) as:

$$REQ\_DS = \left\lceil \frac{Data(bits)}{48} \right\rceil \quad (4)$$

2) Contention Access Period (CAP): After the expiry of CP, CAP commences. CAP is fixed and comprises of 256 CSD. During CAP, those nodes who could not become member of the network during setup phase can become a member of this network. These non member nodes send JOIN_REQ message to the CH by following slotted CSMA/CA algorithm and in response CH only acknowledges these nodes that their requests have been reached to the CH. Successful nodes who become member of this network are informed in the next ADS_ANN message.

3) Allocation Data Slot Announcement (ADS_ANN) Message: After CAP, CH's ADS_ANN message starts. It is mandatory for all member nodes to listen this message not only to synchronize with the CH but also to attain necessary information. ADS_ANN message comprises of:

1) List of new members who's JOIN_REQ has been accepted by allocating them a unique short address of 8 bits along with their control slot numbers.

2) List of all those source nodes which have been assigned data slots in order to transmit its data. This includes short address of data requesting node, initial data slot number along with number of data slots allocated to each source node. In case, CH does not receive a data request from a member node, then CH’s DSA_ANN frame only informs the start time of its next control period to that node. Priority of source nodes are determined by applying knapsack algorithm. Maximum Data Slot Duration (DSD_MAX) allowed in a session is:

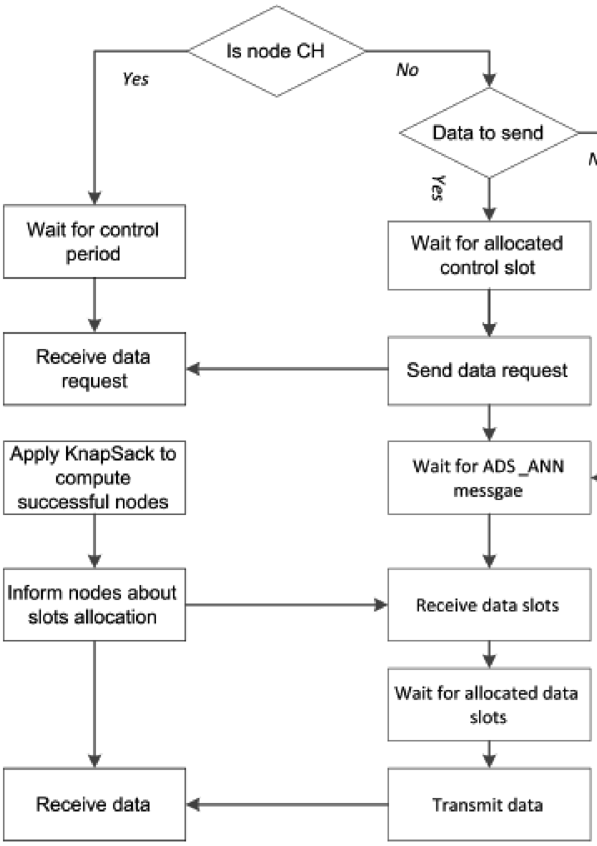


Fig. 4. Data transmission process during steady state phase.

$$DSD\_MAX = CSD \times 2^{16} \quad (5)$$

In case, if requested number of data slots increase from maximum limit then some of the requested data will not be entertained during that session. Complete data transmission process from node to CH is shown in Fig.4

3) Nodes are also informed about the Start of CP (CP_START) by simply providing a 16 bits information about total data slots assigned (DSA_TOT). As, each member node already knows about its allocated control slot number, when their membership was confirmed by the coordinator, So nodes only need to know about the CP_START which can be calculated as:

$$CP_{START} = DSA\_TOT \times 256 \quad (6)$$

C. Knapsack Optimization Algorithm

In our proposed BEST_MAC, allocation of data slots to the source nodes are prioritized on the basis of Knapsack Optimization algorithm with following modifications.

1) W : Total knapsack weight or total available slots.

2) w_i: Number of slots requested by i_{th} node.

3) w: current slot number which ranges from 0 to W. If coordinator receives j slot requests from v nodes, then it checks whether total requested slots are more than the available slots or not. If j slots are less than W then all requesting nodes are assigned data slots as per their requests but their priorities are determined by the knapsack algorithm. However, if

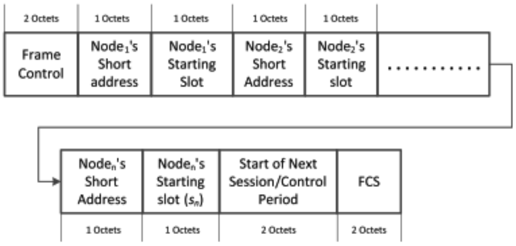


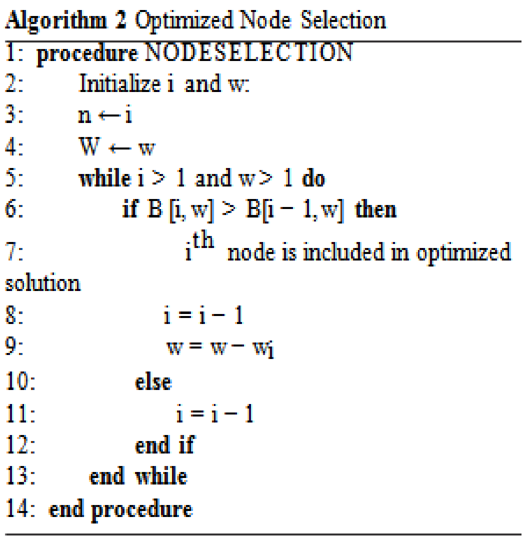
Fig. 5. ADS_ANN Message Format.

requesting data slots increases than the available slots, then CH scrutinize source nodes which can transmit data during that session via knapsack as follows.

The knapsack problem is solved in terms of solving sub-problems with the help of knapsack algorithm. Let, C[i, w] represent the maximum slots of a subset S_i with slots w and C[v, W] is the required optimal solution, where v represents the nodes, which are successfully allocated CFP slots and W is the slot capacity which must be less or equal to the total slot capacity.

Algorithm 1 EEBTMAC Algorithm

```
procedure KNAPSACK TABLE IMPLEMENTATION
    $w \leftarrow$ Current slot
    $W \leftarrow$ Max. no. of slots
    $i \leftarrow$ Node ID
    $n \leftarrow$ Max. no. of nodes
    $B[i, w] \leftarrow$ Cell value of $i^{th}$node with w slot
    $w_i \leftarrow$ No. of slots required or requested by $i^{th}$ node
    for $w = 0$ to W do
        $B[0, w] = 0$ // Initialize 1st row to 0's
    end for
    for $i = 1$ to v do
        $B[i, 0] = 0$ // Initialize 1st column to 0's
    end for
    for $i = 1$ to v do
        for $w = 0$ to W do
            if $w_i \leq w$ then
                if $w_i + B[i-1, w-w_i] > B[i-1, w]$ then
                    $B[i, w] = w_i + B[i-1, w-w_i]$
                else
                    $B[i, w] = B[i-1, w]$
                end if
            else
                $B[i, w] = B[i-1, w]$
            end if
        end for
    end for
end procedure
```



Algorithm 2 Optimized Node Selection

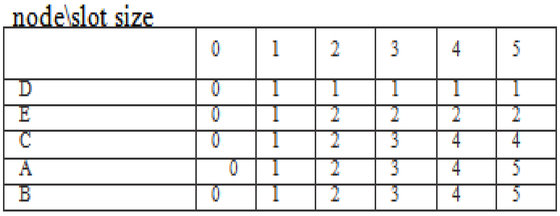
```
procedure NODESELECTION
    Initialize i and w:
    $n \leftarrow i$
    $W \leftarrow w$
    while $i > 1$ and $w > 1$ do
        if $B[i, w] > B[i-1, w]$ then
            $i^{th}$ node is included in optimized solution
            $i = i - 1$
            $w = w - w_i$
        else
            $i = i - 1$
        end if
    end while
end procedure
```

Optimized node selection is determined by following algorithm.

a) All the requesting nodes are placed in ascending order on the basis of their requested slots. i.e nodes requesting less slots are treated first as compared to nodes requesting more slots. E.g if five nodes a, b, c, d and e request for 3,4,2,1 and 1 data slots, respectively, then they are ordered as d, e, c, a and b. In case, if two or more nodes have requested for the same number of data slots, then the node with smaller short address gets priority over node having larger value of short address.

b) Weights and values of each node will be same as of its required slots. e.g., value of nodes a, b, c, d and e will be 3, 4, 2, 1 and 1, respectively.

Table.i. filling of knapsack table



node\slot size

	0	1	2	3	4	5
D	0	1	1	1	1	1
E	0	1	2	2	2	2
C	0	1	2	3	4	4
A	0	1	2	3	4	5
B	0	1	2	3	4	5

In knapsack algorithm, we select maximum number of nodes with maximum slots utilization. In order to minimize the delay, a node is required to transmit its data as whole instead of transmitting its data in parts as proposed in BMA- RR [17]. In addition, Energy consumed due to radio toggling in BMA-RR is saved by implementing knapsack optimization technique. By implementing knapsack algorithm, average data completion time of source nodes becomes faster than round robin in a session.

D. Slot Duration

In the proposed scheme, tiny data slots are used as compared to earlier TDMA based MAC protocols. Tiny Slot duration helps in allocating data slots as per requirement of each source node in an efficient manner by minimizing unused time slots portion to source nodes as compared to previous TDMA based schemes. This helps in reducing duration for those source nodes which are waiting for their data to send. In the proposed scheme, for efficient use of time slots, the slot duration is kept smaller as compared to traditional TDMA based schemes. In BEST_MAC, each data slot is a simple multiple of control slot. Excessive delay comparison between BMA-RR and BEST_MAC is shown in Table II, when nodes want to generate random data. Varying data traffic from 5 nodes is transmitted with same data rate. In BMA-RR, each data slot can handle 2000 bits, however data slot of BEST- MAC is 48 bits/slot. The comparison table shows that reduced data slots save substantial time as compared to larger data slots used in BMA-RR. As CH keeps its radio ON to receive data from source nodes throughout these data slots. So smaller data slots also save significant amount of energy and consequently throughput is improved.

E.$_{ch}$Energy)Consumption during SP Total energy consumption during setup phase in N size cluster (E^{setup}) is computed as sum of energy consumed by CH and its associated (N − 1) member nodes. Energy consumption by a CH comprises of energy consumed during Active and Idle states. Energy consumed by CH during active $E_{ch}^{sp-Active}$ is calculated as:

$$E_{ch}^{sp-Active} = P_{ch}^{AT} \times T_{AT} + P_{ch}^{JR} \times T_{JR} \times (N - 1) + P_{ch}^{CS} \times T_{CS} \qquad (7)$$

Where, P_{ch}^{AT} ,P_{ch}^{JR} and P_{ch}^{CS} are the power consumed by the CH in transmitting CH_ANN, receiving JOIN_REQ and transmitting of CS_ALLOC message to all member nodes, respectively. The T_{AT} , T_{JR} and T_{CS} are the time required to send CH_ANN, receive JOIN_REQ and send CS_ALLOC messages, respectively. In same state, the energy consumed by a member node m, $E_m^{sp-active}$, where m ∈ (N − 1), is calculated as:

$$E_m^{sp-Active} = P_m^{AT} \times T_{AT} + P_m^{JR} \times T_{JR} + P_m^{CS} \times T_{CS} \qquad (8)$$

where, P_m^{AT} ,P_m^{JR} and P_m^{CS} are the power consumed by the member node for receiving CH_ANN, sending JOIN_REQ and receiving CS_ALLOC messages, respectively In a N nodes cluster, there are N − 1 member nodes. If $E_{am}^{sp-active}$ is energy consumed by all member nodes during active mode then it is computed by eq.(9).

$$E_m^{sp-Active} = \sum_{i=1}^{N-1} E_i \qquad (9)$$

During SP, energy is also consumed during idle listening period of CH and its member nodes. If $P_{ch}^{sp-idle}$ is the power consumed by CH during idle state as it has to keep its receiver ON to receive member node's JOIN_REQ messages $T_{ch}^{sp-idle}$ is the time for idle period, then total energy consumed by CH during idle period during SP($E_{ch}^{sp-idle}$) is computed as

$$E_{ch}^{sp-Idle} = P_{ch}^{idle} \times T_{ch}^{SP-Idle} \qquad (10)$$

All member nodes after sending JOIN_REQ messages to CH, turns their radios ON to receive CH's CS_ALLOCmessage from CH. At the start of SP, member nodes remain in idle mode to receive CH_ANN message from CH, as shown in Fig.3. If a member node m consumes ($P_m^{sp-idle}$) Power and has ($T_m^{sp-idle}$) idle listening period then the overall energy consumption of a member node m during idle listening period in SP ($E_m^{sp-idle}$) is computed as

$$E_m^{sp-idle} = P_m^{SP-Idle} \times T_m^{SP-Idle} \qquad (11)$$

Total energy consumed by N − 1 member nodes during idle mode in SP ($E_{am}^{sp-idle}$) is calculated as

$$E_{am}^{sp-idle} = \sum_{i=1}^{d} E_i^{SP-Idle} \qquad (12)$$

Total energy consumption in a cluster during setup phase, E^{Setup} is computed as in eq. (13):

$$E^{Setup} = E_{ch}^{SP-Active} + E_{am}^{SP-Active} + E_{ch}^{SP-Idle} + E_{am}^{SP-Idle} \qquad (13)$$

F. Energy Consumption during SSP

A round comprises of one SP and one SSP. SSP is divided into multiple sessions and each session comprises of a control period followed by CAP, data slot allocation period and dedicated data slots for communication. In session j, source node(s) send their data request(s) during its their allocated control slot by transmitting DATA_REQ message(s), during their allocated control slot, whereas all the other nodes keep their radios off to save energy. Energy consumed by a source node during session j, ($E_s^{C\,Pj}$) of a control period is computed as:

$$E_s^{CP_j} = P_s^{CP_j} \times T_s \qquad (14)$$

here, ($P_s^{C\,Pj}$) message and T_S is the control slot duration during session j. CH throughout this control period remains in receiving mode by keeping its radio ON to receive DATA_REQ messages. For source nodes x, energy consumption during control period (E$^{C\,Pj}$) is computed as:

$E^{CP_j} = E_s^{CP_j} \times x + (N-1-x) \times P_{ch}^{CP-Idle_j} \times T_s + x \times P_{ch}^{CP-Rx_j} \times T_s$ (15)

Here $(P_{ch}^{C\,P-Idlej})$ is power consumed by CH during idle listening in the control period and P_{ch}^{CP-Rxj} is power consumed in receiving DATA_REQ message during control period by CH. Control period is followed by contention access period in which those nodes who are in the range of CH and wants to become member send their JOIN_REQ to CH during this period and CH acknowledges to verify that request has been successfully received. Energy consumed by CH in session j during CAP is calculated as:

$E_{ch}^{CAP_j} = P_{ch}^{JR_j} \times T_{JR} + P_{ch}^{ACK_j} \times T_{ack} + P_{ch}^{CAP_{idle}\,j} \times T_{ch}^{CAP_{idle}}$ (16)

Here (P_{ch}^{JRj}), (P_{ch}^{ACKj}), and $(P_{ch}^{CAPidlej})$ are the power consumed in recieving JOIN-REQ, sending acknowledgement and during idle state respectively . whereas T_{ack} and T_{idle} are time required to send acknowledgment and idle time of CAP during CAP respectively. If (P_{nm}^{JRj}), (P_{nm}^{ACKj}), and $(P_{nm}^{CAPidlej}$ idle) are power consumed in sending JOIN_REQ message, receiving acknowledgment message and power consumed in waiting for acknowledgment messages, respectively during session j, then Energy consumed by a non member node $E_{nm}^{CAP\,j}$ during j session of CAP is calculated as:

$$E_{nm}^{CAP\,j} = P_{nm}^{JR_j} \times T_{JR} + P_{nm}^{ACK\,j} \times T_{ack} + P_{nm}^{CAP\ idle\ j} \times T_{nm}^{CAP\ idle} \quad (17)$$

Here, $T_{nm}^{C\,AP}{}_{idle}$ is the time when non member node remains in idle state. If d nodes want to be a part of this network, then total en ergy consumed during CAP in j session (E^{CAPj}) is computed as:

$E^{CAPj} = \sum_{i=1}^{d} E_{nm}^{CAPj} + E_{ch}^{CAPj}$ (18)

Contention access period is followed by data slots allocation period. During this period, CH informs all source nodes about their allocated data slots by sending ADS_ANN message. ADS_ANN message also includes the information about start of next control period. Total energy consumed during data slots allocation period in session j, (E^{ADSj}), is calculated as:

$$E^{ADSj} = P_{ch}^{ADSj} \times T^{ADSj} + \sum_{i=1}^{N-1} P_i^{ADS\,-Rxj} + T^{ADSj}$$

(19)

where, P_{ch}^{ADSj} is power consumed by a CH in transmitting ADS_ANN message, ADS_ANN message, P_i^{DSA-Rx} is power consumed by node i to receive that message, and T^{ADSj} denotes the time required to send and receive ADS_ANN message during session j. Now, we calculate the energy consumed by all source nodes to transmit data in session j, if out of x nodes, y nodes have been successfully allocated time slots then E_{SN}^{DTj} is determined as:

$E_{SN}^{DTj} = \sum_{i=1}^{y} P_i^{DTj} \times k \times T^{CS}$ (20)

here, k are number of data slots and (P_i^{DTj}) power consumed in transmitting data by source node i in session j.Energy consumed by a CH in receiving all data packets, (E_{ch}^{DTj}) ,from the source node during the same session is computed as

$E_{ch}^{DTj} = P_{ch}^{DRj} \times k \times T^{DS}$ (21)

where is (P_{ch}^{DRj}) power consumed by CH in receiving data packets from all source nodes during session j. Therefore, the overall energy consumption during session j, (E_J^{Steady}), is:

$E_j^{Seady} = E^{CP\,j} + E^{ADS\,j} + E^{CAP\,j} + E^{DT\,j} + E_{ch}^{DT\,j}$ (22)

For q steady state sessions in a round, total energy consumed during steady state sessions SSP(E^{Steady}) is:

$E^{Steady} = \sum_{j=1}^{q} E_j^{Steady}$ (23)

Total energy consumed in round of a cluster (E_{total}) is sum of energy consumed in SP as well as in SSP and is computed as:

$E_{total} = E^{Setup} + E^{Steady}$ (24)

IV. SIMULATION ANALYSIS

This section discusses the simulation analysis of our pro- posed EEBTMAC protocol in contrast with conventional scheme such as E-TDMA [8] and BMA-RR [17]. As we discussed that our proposed EEBTMAC protocol improves throughput, minimizes delay and increases energy efficiency of the whole network. To evaluate and validate the effectiveness of the proposed EEBTMAC protocol, we compared through- put, energy efficiency and delay with E-TDMA and BMA- RR in respect of varying probability and number of sessions. During simulations, we considered a different size network, off which one node acts as CH and rest as member nodes. These nodes are deployed in an area of 100 ×100 meters. Probability P is set on the basis of nodes having data requests, that is, if P = 0.1, then only 10% member nodes are allowed to send data. Random data traffic is generated by source nodes within the range of 175 Bytes to 2.85 KB. Rest of the simulation parameters are shown in Table III.

Parameters	BEST-MAC	BMA-RR	E-TDMA
Data rate (bps)	24000	24000	24000
control Packet Size (bits)	48	144	1
Control Slot Length (sec)	0.002	0.006	0.00004166
Data Slot Length (sec)	0.002	0.083	0.083
Transmitting Energy (nJ)	50	50	50
Receiving Energy (nJ)	50	50	50
Idle Energy (nJ)	5	5	5

Table.III Simulation Parameters

A. Transmitted Data

The transmitted data is calculated as the amount of data successfully sent from source to the destination node.

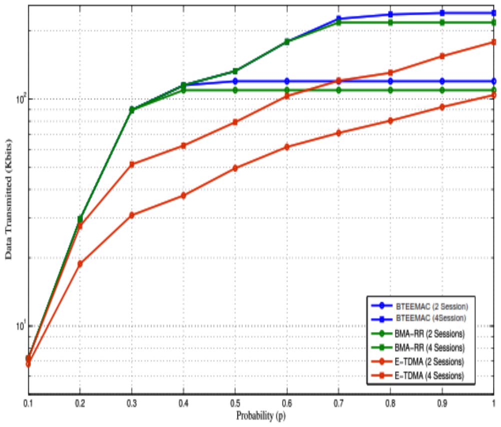


Figure 6. Transmitted data versus probability (P) for 2 and 4 sessions.

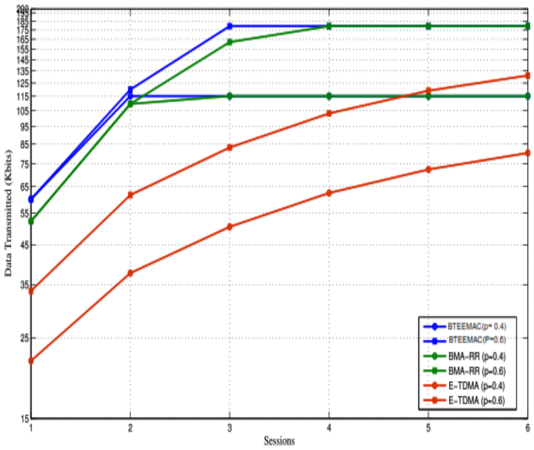


Figure 7. Transmitted data versus session for P = 0.4 and 0.6.

Figure 6 and 7 show the transmitted data for varying probability (P) and sessions, respectively. It is evident from the results that EEBTMAC transmits more data as compared to E-TDMA and BMA-RR. In Fig. 6, probability of source nodes are increased for 2 and 4 session, the results show that, EEBTMAC transmits more data as of the other two MAC protocols when number of source nodes increases in both scenarios. It has been observed that EEBTMAC is unable to transmit more data, when P increases from 0.4 and 0.9 for 2 and 4 sessions, respectively. This is because, all of its data slots are already occupied. In Fig. 7, performance of MAC protocols is determined for varying sessionswith P = 0.4 and P = 0.6. This helps in analyzing EEBTMAC performance when amount of data required to send is less than the available number of data slots. It is obvious from the results , EEBTMAC sends the required data prior to other two MAC protocols. Results further show that EEBTMAC transmits more data as of the other two MAC protocols during first 2 and 3 sessions for P = 0.4 and P = 0.6 respectively. However, when session increases from 3 and 4 for 0.4 and 0.6 probabilities, then BMA-RR and EEBTMAC are unable to transmit further data. This is because of source nodes have already sent their data, where as ETDMA keeps on transmitting its data as it is unable to transmit the same amount of data even in 6 sessions. It is evident from the results that EEBTMAC perform better in transmitting more data as of other two protocols in each network size. It is noticed that average improvement in transmitted data by EEBTMAC is 10.1% and 34.2% for 2 sessions and 9.5% and 15% for 4 sessions as compared to BMA-RR and ETDMA respectively, refer Fig. 6. This significant improvement in transmitted data by EEBTMAC is due to the selection of smaller data slots and implementing knapsack optimization technique, which increase the link utilization by accommodating different data requirements effectively. Whereas, in other two conventional TDMA based MAC protocols, larger data slots are used that cannot accommodate adaptive data traffic requirements efficiently.

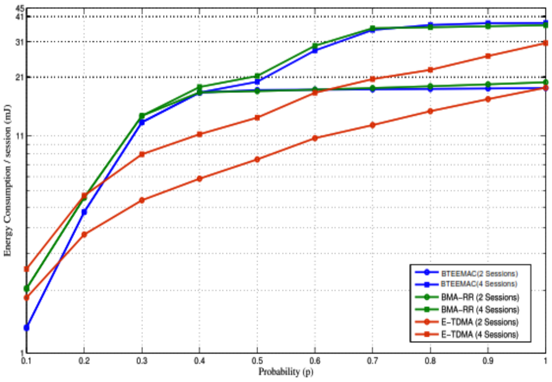


Figure 8. Energy consumption of the network versus P for 2 and 4 Sessions.

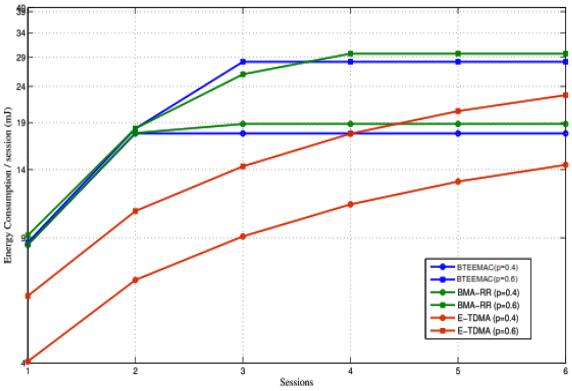


Figure 9. Energy consumption of the network versus sessions for P = 0.4 and 0.6.

B. Total Energyc onsumption

Energy consumption of sensor nodes effects the life cycle of a WSN. Total energy consumption versus probability and sessions are shown in Fig. 8 and 9, respectively. Figure 8 shows, that, when probability approaches to 0.3 and 0.6 for 2 and 4 sessions, EEBTMAC consumes less amount of energy as of BMA-RR while transmitting same data traffic. At P = 0.4 and P = 0.7 for 2 and 4 sessions, the energy consumption of both EEBTMAC and BMA-RR are almost same. This is due to the fact that at this stage EEBTMAC transmitted more data as of BMA-RR. However, energy consumption of ETDMA is less than other two, This is because of transmitting less amount of data as compared to the other two MAC protocols. The similar behavior is also observed in Fig. 9. Here, EEBTMAC conserve more than 5% energy while transmitting same amount of data as of BMA-RR. However ETDMA follows the same trend as it consumes less amount of energy than the other two protocols because of transmitting less amount of data.

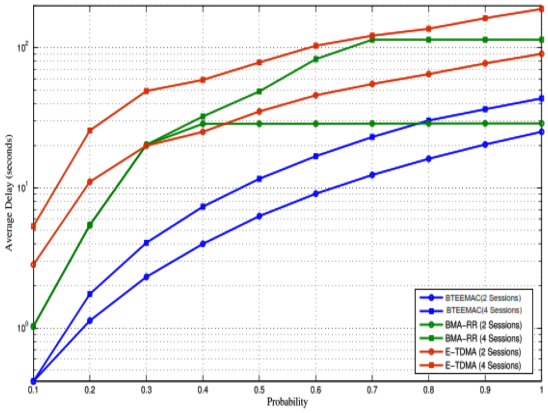


Figure 10. Transmission Delay of the network versus P for 2 and 4 Sessions.

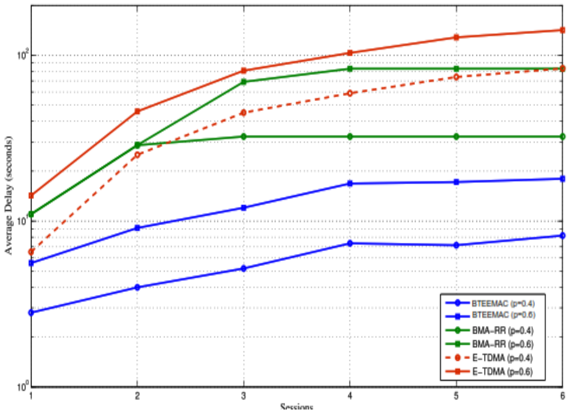


Figure 11. Transmission Delay of the network versus sessions for P = 0.4 and 0.6.

C. Transmission Delay

Transmission delay of a node is the time, when it has a data request till the successful transmission of data. Figures 10 and 11 show the transmission delay versus P and session, respectively. It is obvious from the results, that EEBTMAC has significantly less transmission delay as of BMA-RR and E-TDMA. This is due to the implication of knapsack algorithm, which helps in allowing more nodes to transmit their data at once instead of transmitting in parts. This results in avoiding more nodes to keep data in their buffer for longer time, as described in section III-C. Smaller slot length further helps in improvement of the network delay, as shown in Table 2.

The results in Fig. 10 show that average transmission delay of the network is minimized by EEBTMAC upto 57% and 7% for 2 sessions and 73% and 81% for 4 sessions, compared to BMA-RR and E-TDMA, respectively. Same pat- tern is also observed for varying sessions as shown in Fig. 11.

V. CONCLUSION

In this work, we proposed a TDMA based MAC protocol (named as EEBTMAC) for WSN that can support applications of smart cities, where adaptive data traffic is required. The protocol adaptively handles the varying amount of data traffic by using large number of small size data slots. In addition, it implements Knapsack optimization technique for better link utilization as well as, to reduce node's job completion time that results in significant improvement in average packet delay of nodes. Energy consumption is also minimized by reducing the control overhead by introducing a unique 1 byte short address to identify the member nodes. The performance of the proposed EEBTMAC protocol is compared with the BMA-RR and E-TDMA through simulations. It shows that EEBTMAC achieves more than 70% and 80% efficiency in data transmission delay and more than 7% and 17% data is transmitted compared to BMA-RR and E-TDMA without compromising energy consumption.

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