BSMAC: A hybrid MAC protocol for IoT systems

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***Abstract*—This paper proposes a new medium access control (MAC) protocol for low power sensor devices, suitable for IoT systems. IEEE 802.15.4 standard is suitable for low power wireless personal area network (WPAN) but it does not satisfy the data rate and reliability requirements for IoT systems in a 5G wireless network. We have observed that unnecessary packet drop takes place due to beacon superframe broadcasting during data transmission and it is the primary reason for the standard's data-rate and reliability shortfall. This problem represents a scenario where data transmission takes place with the lack of available time for data transmission in that superframe duration. To overcome this lacuna, we incorporate backoff freezing mechanism, where the backoff counter freezes whenever the available time for data transmission is insufficient in that superframe duration. A novel sleep protocol is designed to reduce power consumption in idle states too. The proposed MAC protocol is modeled using a 3-dimensional Markov chain for analytical performance evaluation. Analytical results are verified with the simulation run in ns-2.35. Proposed MAC with sleep protocol significantly outperforms the existing state-of-the-art protocols.**

***Index Terms*—WPAN, IoT, MAC, Sleep protocol, Backoff freezing, IEEE 802.15.4**

I. INTRODUCTION

With upcoming 5G, communication systems will attain unprecedented heights and it is a big step towards the virtualization of our daily life. Fully functioning 5G will support virtual control over household works, transportation systems, health checkup to energy management, environmental sensing, and all of these come under the name of Internet of Things (IoT). IoT products and systems can be broadly classified into five categories: smart wearable, smart home, smart city, smart environment, and smart enterprise. Understandably, IoT has the potential of high socio-economic impact. However, it requires a complete modification over existing communication protocols to satisfy the requirements of achievable data rate, reliability, and energy efficiency [1]. Existing researches mainly focus on using IEEE 802.15.4 standard for IoT network.

However, it is observed that during high traffic the existing IEEE standard gives degraded performance due to low reliability and correspondingly low throughput and high latency. This reflects the incident of packet drop due to beacon broadcasting, which takes place due to data transmission without enough remaining time in the present superframe duration. To overcome this shortfall, backoff freezing and sleep protocol MAC (BSMAC) is proposed. BSMAC freezes the backoff counter whenever there is a lack of time in the present superframe duration for data packet transmission and goes to a low-power sleep state. After a certain period, IoT device wakes up from the sleep state and restarts the backoff counter. However, random sleep time can affect the throughput and power efficiency in a dense IoT network. To resolve this, an optimization problem is defined, which returns optimal sleep period subject to power consumption and throughput. In this paper, we interchangeably use either sensor or IoT device.

A. Contribution

The contributions of our article can be summarized as follows:

- We propose BSMAC, that employs backoff freezing mechanism to increase reliability and throughput and decrease power consumption. BSMAC is analytically modeled using a three dimensional Markov model.
- A novel sleep protocol is used to reduce power consumption during backoff freezing period.
- An optimization problem is defined to obtain the optimal sleep period.
- Performance of BSMAC is evaluated with the help of extensive simulation results. Simulation results are obtained using ns-2.35 for varying offered load and finally the results are compared with works from existing literature.

B. Paper Organization

A literature survey, underlining the existing works and their shortfalls are given in Sec. II. We introduce proposed BSMAC, details and basic. In Sec. III, we present a three-dimensional discrete time Markov model (DTMM) to obtain closed-form analytical expressions of the performance metrics. Analysis of the DTMM model of BSMAC and the proposed sleep protocol is given in Sec. III too. In Sec. IV, we define the optimization problem to calculate the optimal period between two successive channel sensing. Analytical and simulation results for different performance metrics, e.g., reliability, power consumption, throughput, and delay are given in section V. Comparing the results of the BSMAC with IEEE 802.15.4 standard and two existing works, it is observed that there is a trade-off between reliability and power consumption. Section VI describes the scope of future work and concludes the paper.

II. RELATED WORK

The first IEEE standard to support the Wireless Personal Area Networks (WPAN) was 802.15.4 [2]. There had been several simulation-based studies [3], as well as analytical works [4] to investigate the delay, throughput, and power consumption performance of IEEE 802.15.4. In papers [5], [6], TCP-like window adjustment mechanisms were applied for IEEE 802.15.4. In these works, the algorithm adapted the contention window size depending on the successful packet transmission, packet collision, and channel sensing state. From these works, it was evident that throughput, reliability, and delay were not even close to the 5G requirements [7]. The viability of IEEE 802.15.4 standard for IoT requirements in the presence of node mobility is another important aspect and the work of Al-Nidawi *et al.* suggested that the standard's perform was satisfactory for IoT systems [8]. There are few works on duty cycle optimization, where duty cycle is the ratio of active period in the superframe or superframe duration and beacon interval [9]. However, our argument for BSMAC is valid after duty cycle optimization and discussed in details in Sec.III-D.

There were few other works on developing a standardized framework for IoT systems. Wang *et al.* proposed a work on spectrum sensing subsystem for IoT medical applications [10]. Shrestha *et al.* in their seminal work proposed a framework for integrating different IoT applications with an MAC protocol. A theoretical comparison of different cellular IoT standards was investigated in [11]. However, these standards should be validated by detailed simulation based studies as well.

From the performance study of the existing works we can infer that, the efficient utilization of superframe periods still remains a matter of concern as the performance at high traffic volume is unsatisfactory, and it leads to our proposition of BSMAC protocol, that aims to utilize the superframe period judiciously by incorporating backoff freezing mechanism and a novel sleep protocol. The concept of backoff freezing is used in IEEE 802.11 and 802.15.6 standard depending on clear channel assessment. However, in this article backoff freezing is implemented as a function of 'remaining time in the superframe duration'.

III. BSMAC ALGORITHM

A. Philosophy

BSMAC is an extension of IEEE 802.15.4 standard with backoff freezing and efficient utilization of inactive period. Therefore, the physical layer specifications and data or control frame formats remain same. Basic difference between the IEEE 802.15.4 standard and BSMAC is in functioning during backoff waiting — *existing standard keeps decreasing the backoff state and performing clear channel assessment even with the lack of available time in the superframe duration, while the latter one avoids these unnecessary activities and increases the power efficiency.*

B. Network Model

Architecture of a generic IoT network is given in Fig.1. Here BS represents base-station, S_i represents the low-power sensors, and PANC stands for personal area network coordinator. Few sensors and a PANC form a femto or pico-cell network, and single-hop communication is used between the PANC and sensor. PANCs are capable of forwarding small data bursts at a high data rate to the neighboring PANC or BS directly. For easier interpretability, we consider a single cell with multiple sensors and a PANC, which is directly connected to the BS. The superframe structure of the MAC protocol is shown in Fig.1 too.

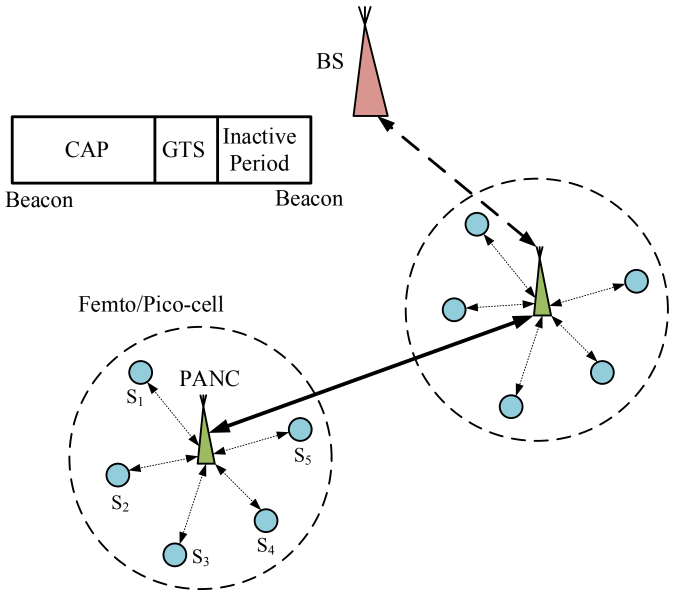

Fig. 1: IoT Network Architecture and superframe structure

C. Propagation Model

Sensors forward the data to the PANC using 2.4 GHz ISM band and then it is further forwarded to the BS. As PANC forwards the data in burst, therefore, to satisfy 5G requirements, a greater throughput of the small-cell is primary concern. A method of increasing the throughput is effective utilization of the access period time slots. Channel access to the sensors are given using CSMA/CA algorithm with backoff exponent, and beacon synchronization is used to maintain a common clock.

D. Illustrative example

From the superframe structure shown in Fig.1, data transmission takes place during CAP (contention access period) and GTS (guaranteed time slot), and the sensor goes to a low power state during the inactive period. Assume that after beacon synchronization, sensors S_1, S_3, and S_4 will transmit data and it takes 0.6(CAP+GTS), 0.5(CAP+GTS), and 0.2(CAP+GTS) time respectively to forward the data to PANC. We also assume that initially S_3 gets access to the channel, and S_4 gets access next. Now even if S_1 gets access to the channel in this superframe duration, it will be unsuccessful as beacon synchronization takes place in between. Therefore in BSMAC, once remaining time in the superframe is less than 0.6(CAP+GTS), S_1 goes to the sleep state. One important

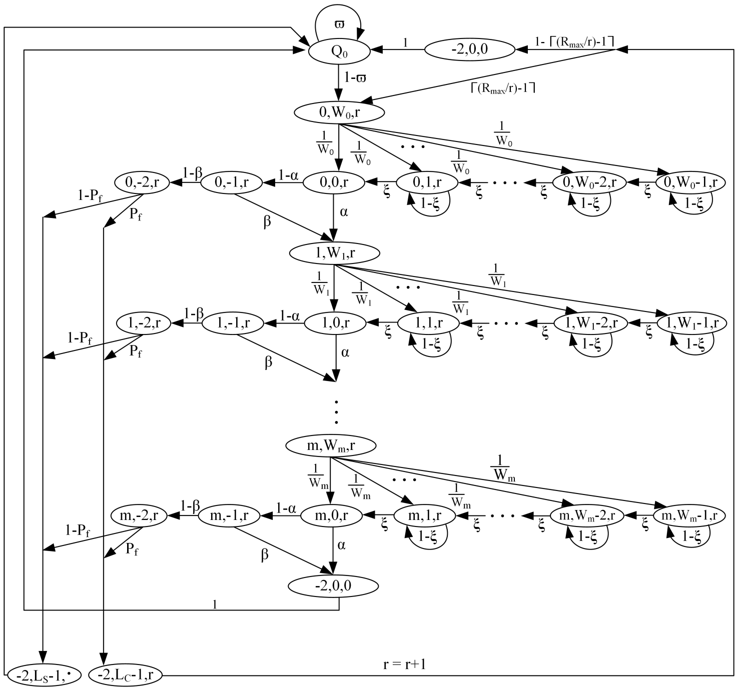

Fig. 2: Markov chain model for BSMAC without sleep protocol

detail is always associated with backoff freezing and sleep protocol, data packet overflow. Due to limited storage new observations or measurements can get dropped, while the old observations remain at the buffer. To resolve this, BSMAC accounts for the state of buffer and accordingly calculates the sleep period.

Now, $CAP + GTS$, alternatively mentioned as superframe duration, is the total time duration that can be used to transmit a data. Optimization of duty cycle and synchronization is modifying this superframe duration, therefore, our argument for BSMAC holds true and BSMAC can be used along with duty cycle or synchronization optimization to further enhance the performance.

IV. DTM MODEL FOR BSMAC

The symbols used throughout in the paper are tabulated in Table.I. We use DTMM to analyze the functionalities of BSMAC. The Markov chain model for backoff freezing mechanism is shown in Fig. 2. The Markov chain is modeled using three stochastic parameters, $b(t), c(t)$ and $r(t)$, representing backoff state, state of backoff counter and state of retransmission counter respectively. Objective of this DTMM is to obtain the analytical reliability, throughput and energy consumption of a sensor using the BSMAC. The stationary distribution of the Markov model is,

$$S_{i,j,k} = \lim_{t\to\infty} P(b(t) = i, c(t) = j, r(t) = k)$$
$$j \in (-1, max(W_i - 1, L_s - 1, L_c - 1)), k \in (0, r) \qquad (1)$$

The state transition probabilities are,

$$P(Q_0 \mid Q_0) = \varpi \qquad (2)$$

TABLE I: Notations and Descriptions

Notation	Description
α	Probability of busy channel in first channel sensing
β	Probability of busy channel in second channel sensing
ϖ	Probability that the sensor has no packet to transmit
W_i	Size of contention window
γ	Probability of idle-state
m	Maximum number of backoff stages
$\overline{m}$	Average number of backoff stages used in a packet delivery
P_f	Probability of failure
ξ	Probability of having sufficient time for data transmission in the superframe
Ψ	Probability of buffer overflow
P_{cf}	Probability of packet drop due to channel access failure
P_{cr}	Probability of packet drop due to retransmission limit
R_{max}	Maximum frame retransmission limit
L	Length of the transmitted packet (header length+payload)
L_p	Slot length of the transmitted packet
L_s	Slot length for successful packet delivery
L_c	Slot length for determining collision probability
L_{I-Ack}	Slot length of the immediate acknowledgement (I-Ack) frame
L_{RTT}	Slot length of round trip time
D_b	Average delay due to backoff
R	Reliability of a sensor
S	Throughput of a sensor
N	Number of sensors in WBAN
E_t	Average energy consumption
E_{idle}	Energy consumption in idle state
E_{tx}	Energy consumption for data transmission
E_{tx}	Energy consumption for data reception

$$P(0, W_0, r \mid Q_0) = 1 - \varpi \qquad (3)$$

$$P(i, j, k \mid i, W_i, k) = \frac{1}{W_i}$$
$$\text{for } j \in [0, W_i - 1], i \in [0, m], k \in [0, R_{max} - 1] \qquad (4)$$

$$P(i,j-1,k \mid i,j,k) = \xi \tag{5}$$

$$P(i,j,k \mid i,j,k) = 1-\xi \tag{6}$$

$$P(i,0,k \mid i,W_i,k) = \frac{1}{W_i}\Big(\frac{1-\xi^{W_i-1}}{1-\xi}\Big) \tag{7}$$

$$P(i,-2,k \mid i,0,k) = (1-\alpha)(1-\beta) \tag{8}$$

$$P(i+1,W_{i+1},k \mid i,0,k) = \alpha+(1-\alpha)\beta, \text{ for } i \in [0,m-1] \tag{9}$$

$$P(-2,L_s-1,k \mid i,-2,k) = 1-P_f \tag{10}$$

$$P(-2,L_c-1,k \mid i,-2,k) = P_f \tag{11}$$

$$P(-3,0,0 \mid -2,L_c-1,k) = 1-\lceil (R_{max}/k)-1 \rceil \tag{12}$$

$$P(0,W_0,k \mid -2,L_c-1,k) = \lceil (R_{max}/k)-1 \rceil \tag{13}$$

Eqn.2 denotes the probability of idle state waiting, Q_0 is a state where the sensor does not have any data packet for transmission. Now for probability $1-\varpi$ the sensor moves to the state of initializing backoff counter, this is represented by Eqn.3. Eqn.4 depicts the probability of randomly selecting the value of backoff counter. If there is enough time for data transmission in the present superframe, backoff counter is decreased. As the probability of having sufficient time for data transmission is ξ, hence the probability of backoff counter decrement is given by Eqn.5. Similarly the probability of remaining in the same backoff state is $(1-\xi)$, shown in Eqn.6. Combining Eqns.4, 5 and 6 we obtain Eqn.7, that stands for the probability of the sensor being in channel sensing state. Eqns.8 and 9, respectively stand for the successful clear channel assessment and unsuccessful clear channel assessment, and correspondingly the value of backoff counter is increased by one for the latter one. Probability of successful and unsuccessful data transfer is given by Eqns.10 and 11, respectively. Packet drop due to retransmission limit and state transition due to packet transmission failure till maximum retransmission value are denoted by Eqns.12 and 13 respectively. The closed form solutions of the DTM using chain regularities are given below. Generalizing Eqn.7 we can write,

$$S_{i,j,k} = \frac{W_i-j+1}{\xi W_i}S_{i,0,k}$$
$$\text{where } i \in (0,m), j \in (0,W_i-1), k \in (0,R_{max}-1) \tag{14}$$

Using Eqn.9 we obtain the following relation,

$$S_{i,W_i,k} = (\alpha+(1-\alpha)\beta)S_{i-1,0,k}$$
$$\text{where } i \in (1,m), k \in (0,R_{max}-1) \tag{15}$$

From Eqns.8, 10 and 11 we obtain following two relations,

$$S_{-2,L_s-1,k} = (1-\alpha)(1-\beta)(1-P_f)S_{i,0,k}$$
$$\text{where } i \in (0,m), k \in (0,R_{max}-1) \tag{16}$$

$$S_{-2,L_c-1,k} = \Big((1-\alpha)(1-\beta)P_f\Big)S_{i,0,k}$$
$$\text{where } i \in (0,m), k \in (0,R_{max}-1) \tag{17}$$

Eqn.12 gives the following relation,

$$S_{-3,0,0} = \sum_{k=0}^{R_{max}-1} S_{-2,L_c-1,k+1}\Big(1-\lceil\frac{R_{max}-1}{k}\rceil\Big) \tag{18}$$

The normalization condition can be written as,

$$\sum_{i=0}^{m}\sum_{j=0}^{W_i-1}\sum_{k=0}^{R_{max}-1} S_{i,j,k} + \sum_{i=0}^{m}\sum_{k=0}^{R_{max}-1} S_{i,W_i,k}$$
$$+\sum_{k=0}^{R_{max}-1}\Big(S_{-2,L_c-1,k}+S_{-2,L_s-1,k}\Big)+Q_0 = 1 \tag{19}$$

Now each term in Eqn. 19 is derived separately. The first term can be expressed as,

$$S_{i,j,k} = \sum_{i=0}^{m}\sum_{j=0}^{W_i-1}\sum_{k=0}^{R_{max}-1} S_{0,0,0}$$
$$= \sum_{i=0}^{m}\sum_{k=0}^{R_{max}-1}\Big(\frac{W_i+\frac{W_i+1}{2}}{\xi W_i}\Big)^k S_{0,0,0}$$
$$= \frac{1-\phi^{R_{max}}}{1-\phi}S_{0,0,0} \tag{20}$$

$$\text{Where } \phi = \frac{1}{\xi}\Big(\frac{W_0+\frac{W_0+1}{2}}{W_0}+\frac{W_1+\frac{W_1+1}{2}}{W_1}$$
$$+\frac{W_2+\frac{W_2+1}{2}}{W_2}+\ldots+\frac{W_m+\frac{W_m+1}{2}}{W_m}\Big) \tag{21}$$

The second term of Eqn. 19 is expressed as,

$$\sum_{i=0}^{m}\sum_{k=0}^{R_{max}-1} S_{i,W_i,k} = \sum_{k=0}^{R_{max}-1}\Big(\frac{3W_0+1}{2\xi W_0}(\alpha+(1-\alpha)\beta)+$$
$$\frac{3W_0+1}{2\xi W_0}\frac{3W_1+1}{2\xi W_1}(\alpha+(1-\alpha)\beta)^2+\ldots+$$
$$\frac{3W_0+1}{2\xi W_0}\frac{3W_1+1}{2\xi W_1}\ldots\frac{3W_m+1}{2\xi W_m}(\alpha+(1-\alpha)\beta)^m\Big)^k S_{0,0,0}$$
$$= \sum_{k=0}^{R_{max}-1}(\chi^k)S_{0,0,0} \tag{22}$$

The third term of Eqn. 19 is expressed as,

$$\sum_{k=0}^{R_{max}-1} S_{-2,L_c-1,k} = \Big[\frac{(1-\alpha)(1-\beta)}{\xi}P_f\Big]\Big(\chi+(1-P_f)\chi^2+$$
$$(1-P_f)^2\chi^3+\ldots+(1-P_f)^{R_{max}-1}\chi^{R_{max}}\Big)S_{0,0,0}$$
$$= \frac{(1-\alpha)(1-\beta)}{\xi}P_f\chi\frac{1-\Big((1-P_f)\chi\Big)^{R_{max}}}{1-(1-P_f)\chi}S_{0,0,0} \tag{23}$$

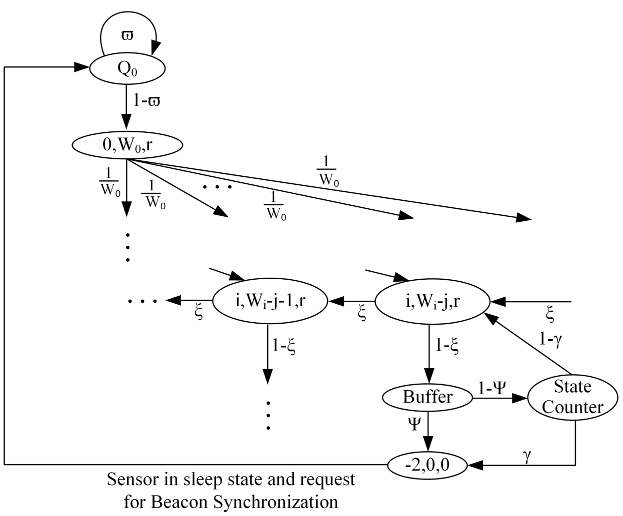

Fig. 3: Sleep protocol in Markov chain model

Similarly,

$$\sum_{k=0}^{R_{max}-1} S_{-2,L_s-1,k} = \frac{(1-\alpha)(1-\beta)(1-P_f)}{\xi} \times P_f \chi \frac{1-\Big((1-P_f)\chi\Big)^{R_{max}}}{1-(1-P_f)\chi} S_{0,0,0} \tag{24}$$

Now the final term of Eqn. 19 can be expressed as,

$$\begin{aligned} Q_0 &= S_{-2,0,0} + S_{-3,0,0} + S_{-2,L_s-1,k} \\ &= \Bigg(\frac{1-(\alpha+(1-\alpha)\beta)^{R_{max}-1}}{1-(\alpha+(1-\alpha)\beta)} + \frac{(1-\alpha)(1-\beta)}{\xi} P_f \chi \\ &\times \Bigg(\chi^{R_{max}-1}(1-P_f)^{R_{max}-1} + (1-P_f) \\ &\times \frac{1-\Big((1-P_f)\chi\Big)^{R_{max}}}{1-(1-P_f)\chi}\Bigg)\Bigg) S_{0,0,0} \end{aligned} \tag{25}$$

Now, combining Eqns. 20- 25, we obtain,

$$\begin{aligned} S_{0,0,0} = \Bigg(&\frac{1-(\alpha+(1-\alpha)\beta)^{R_{max}-1}}{1-(\alpha+(1-\alpha)\beta)} + \frac{(1-\alpha)(1-\beta)}{\xi} \\ &\times P_f \chi \Big((\chi(1-P_f))^{R_{max}-1} + \frac{1-((1-P_f)\chi)^{R_{max}}}{1-(1-P_f)\chi} \\ &\times (1-P_f) + \frac{1-\phi^{R_{max}}}{1-\phi} + \frac{1-\chi^{R_{max}}}{1-\chi}\Big)\Bigg)^{-1} \end{aligned} \tag{26}$$

A sleep protocol can be incorporated to improve the power efficiency of the MAC. The proposed sleep protocol is shown in Fig. 3. In this proposition we introduce the concept of sleep counter and *idle-state factor*. The working principle of the sleep protocol depends on the probability ξ and probability Ψ. For the probability $(1-\xi)$, the condition of the buffer (i.e., how many packets are available for transmission) is checked to determine whether any space is available. For the probability Ψ, the buffer of the sensor is full with data packets and the present packet is dropped to prevent buffer overflow. For the probability $(1-\Psi)$, the sensor remains in sleep state for the optimal sleep period, which can be obtained using a similar optimization problem defined in [12]. Now, *idle-state factor* is a metric that keeps count of how many times the backoff counter remains in the same state. For the probability γ, the counter crosses the threshold limit of remaining in a same state, and the data packet is dropped.

For this sleep protocol, small modification takes place in the derived expressions.

$$\begin{aligned} S_{-2,0,0} &= \frac{1-(\alpha+(1-\alpha)\beta)^{R_{max}-1}}{1-(\alpha+(1-\alpha)\beta)} \\ &+ \sum_{i=0}^{m} \frac{1-\phi^{R_{max}+1}}{1-\phi}(1-\xi)(\Psi+\gamma)(\xi)^i \end{aligned} \tag{27}$$

$$\begin{aligned} S_{0,0,0} = \Bigg(&\frac{1-(\alpha+(1-\alpha)\beta)^{R_{max}-1}}{1-(\alpha+(1-\alpha)\beta)} + \frac{1-\phi^{R_{max}+1}}{(1-\phi)(1-\xi^{m+1})} \\ &\times (1-\xi)^2(\Psi+\gamma) + \frac{(1-\alpha)(1-\beta)}{\xi} P_f \chi \Big((\chi(1-P_f))^{R_{max}-1} \\ &+ (1-P_f)\frac{1-((1-P_f)\chi)^{R_{max}}}{1-(1-P_f)\chi} + \frac{1-\phi^{R_{max}}}{1-\phi} + \frac{1-\chi^{R_{max}}}{1-\chi}\Big)\Bigg)^{-1} \end{aligned} \tag{28}$$

A. Performance Metrics

The different performance metrics, reliability, throughput, delay, and power consumption are stated below:

1) Failure Probability: defined as the probability for which a packet gets dropped, it can happen due to channel access failure and retransmission limit. Hence, mathematically, failure probability is expressed as:

$$P_f = P_{cf} + P_{cr} \tag{29}$$

Retransmission takes place when a transmitted data packet is not successfully received by the receiver.
Now, P_{cf} and P_{cr} are mathematically expressed as:

$$P_{cf} = \sum_{i=0}^{r} (\alpha+(1-\alpha)\beta)^{mi} S_{0,0,0} \tag{30}$$

$$P_{cr} = \sum_{j=0}^{m} (P_f(1-\alpha)(1-\beta))^{rj} S_{0,0,0} \tag{31}$$

2) Reliability: defined as the probability of successful delivery of a transmitted packet. It can also be defined as the complementary probability of packet drop. Therefore, R is symbolically represented as:

$$\begin{aligned} R &= 1 - P_{cf} - P_{cr} \\ &= (1 - \frac{(\alpha+(1-\alpha)\beta)^{m+1}(P_f(1-(\alpha+(1-\alpha)\beta)^{m+1}))}{(1-(\alpha+(1-\alpha)\beta))(1-P_c(1-x^{m+1}))^{r+1}}) \\ &\times S_{0,0,0} \end{aligned} \tag{32}$$

3) Throughput: The *throughput*, S (bits/second) of a sensor is defined as the total amount of bits of successfully transmitted packets in a unit time. Mathematically S can be defined as:

$$S = L \times R \times \tau \tag{33}$$

4) Average Delay: Delay is defined as the time interval from the instant of packet transmission till the ACK for the transmitted data-packet is received. Delay corresponding to a dropped packet is not taken into consideration. Hence, the average delay includes the total time elapsed while a sensor decrements its backoff counter value (until it reaches zero) in each of the backoff stages and the wait duration for the I-ACK frame. Average delay can be expressed as,

$$D = D_b + T_p + T_{I-ACK} + T_{RTT} \tag{34}$$

where D_b denotes the average delay due to backoff counter decrements.

5) Power Consumption: For IoT systems an important performance parameter is the average *power consumption* for individual sensors. It is associated with the average lifetime of the WSN. We calculate the E_t for a sensor as,

$$E_t = (\overline{m} - 1)D_b \times E_{idle} + (\overline{m})L_s \times E_{tx} + E_{rx}(\overline{m} \times D) \tag{35}$$

B. Optimization Problem

The optimization problem in the form of pseudo code is given in Algorithm 1. Here λ, S_{max}, S_{min}, and δ_S represents data rate, maximum sleep period, minimum sleep period, and step size, respectively. τ_S, R_i, S_i, and E_{ti} stands for the calculated sleep period, reliability, throughput, and power consumption, respectively, at each loop. Coefficient C_1 is obtained from Eqn.32.

Algorithm 1 Algorithm for obtaining optimal sleep period

```
function OPTIMAL SLEEP PERIOD($\lambda$, $S_{max}$, $S_{min}$, $\delta_S$)
    $K = (S_{max} - S_{min})/\delta_S$
    for $i = 0$ to $K$ do
        $\tau_S = S_{min} + i \times \delta_S$
        Calculate $\gamma$ and $\overline{m}$
        Update $S_{0,0,0}(\gamma)$
        $R_i = C_1 \times S_{0,0,0}$
        $S_i = L \times R \times \tau$
        $E_{ti} = E_t(\overline{m})$
        if ($S_i < S_{i-1}$ || $E_{ti} > E_{t(i-1)}$) then
            $S_0 = S_{min} + (i-1)\delta_S$
            Break
        else if $S_{min} + (i+1)\delta_S > S_{max}$ then
            $S_0 = S_{max}$
        end if
    end for
    return($S_0$)
end function
```

Finally we obtain the optimal sleep period for which throughput is maximum and power consumption is minimum.

V. PERFORMANCE EVALUATION

In this section we present the simulation results and analyze the performance of BSMAC with and without sleep protocol for various performance metrics, e.g., reliability, power consumption, throughput, and average delay. The input parameters to test the performance of our algorithm in ns 2.35 are given in the table II. The basic parameters are selected from the range of values given in the IEEE standard [2]. We have compared the performance of BSMAC with our previously proposed protocol [12] and the improved protocol suggested by Park et. al [13]. In Figs. 4-7, the simulation results are presented where legend Park, ASMAC stands for the results obtained using model proposed in [13] and [12] respectively. The curves representing BSMAC+sleep and BSMAC stands for our proposed protocol with and without the sleep protocol respectively.

TABLE II: Simulation parameters

Parameter	**Value**
Number of IoT devices (N)	20
Initial size of contention window (W_0)	8
Maximum retransmission limit (r)	8
Minimum backoff exponent (m_l)	3
Maximum backoff exponent (m_h)	5
Maximum CSMA backoffs (m)	4
Acknowledgement size	88 bits
Packet size or Payload	120 bytes

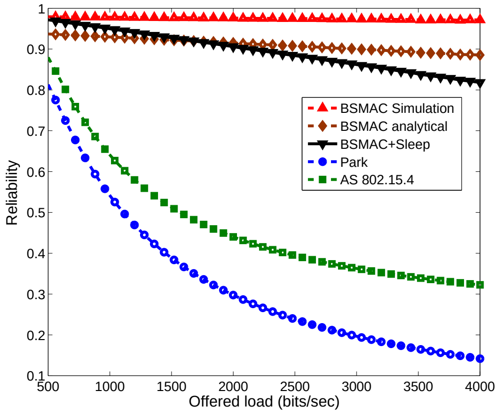

Fig. 4: Reliability vs offered load for 20 sensors

Figure for reliability (Fig.4): From this figure we observe that BSMAC outperforms other state-of-the-art MAC protocols. This observation can be explained using the fact that probability of packet failure is less for BSMAC as it resolves the problem of packet failure due to beacon synchronization. Reliability of BSMAC with sleep protocol is lower than normal BSMAC as packets are dropped with additional γ and ψ probability.

Figure for power consumption (Fig.5): Successful data transmission takes place more reliably in BSMAC, compared to other protocols. Therefore retransmission power consumption is lesser compared to other protocols.

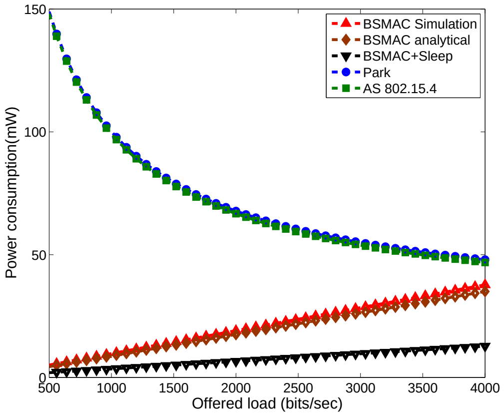

Fig. 5: Power consumption vs offered load for 20 sensors

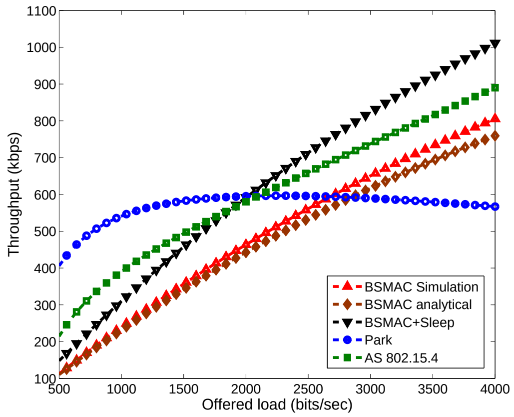

Fig. 6: Throughput vs offered load for 20 sensors

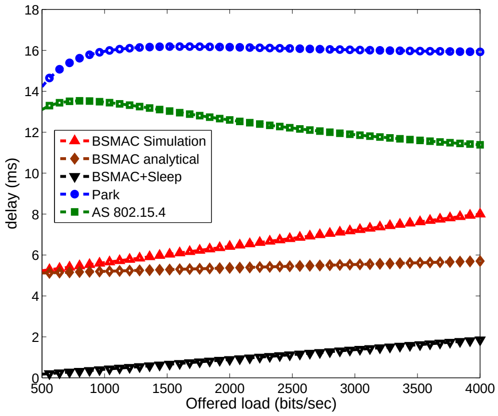

Fig. 7: Delay vs offered load for 20 sensors

Figure for throughput (Fig.6): Throughput is directly proportional with reliability and transmission probability. For normal BSMAC reliability increases but transmission probability decreases. Therefore we observe AS 802.15.4 protocol performs better than BSMAC, even though the latter gives satisfactory performance. However for BSMAC with sleep protocol, for higher offered load, packet drop based on *state of the buffer* highly reduces the delay, and correspondingly effective datarate and throughput increases and outperforms other protocols. **Figure for average packet delay (Fig.7):** The simulation results for delay are observed from the perspective of a hub. For higher traffic, the hub successfully receives the data faster. As reliability and throughput are greater in BSMAC, delay is much lesser here. As BSMAC with sleep protocol reduces delay, it outperforms normal BSMAC in terms of the throughput.

VI. CONCLUSION

In this paper, we presented an improved modified protocol of wireless sensor network based on the IEEE 802.15.4 standard which provides higher reliability, throughput, lesser average packet delay, and lesser power consumption. From the performance analysis we have observed that BSMAC is outperforming the state-of-the-art MAC protocols, and it satisfies the 5G requirements for delay and reliability even for single antenna systems. In future we will explore the effects of BSMAC on multi-antenna devices.

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