Lifetime Prediction of Battery Powered End Device with B-MAC Protocol in Star Configured WSN using OMNeT++

M S Pawar
ARDE, Pashan
Pune-411021, India

J A Manore
ARDE, Pashan
Pune-411021, India

M M Kuber
R&DE(E), Dighi
Pune-411015, India

***Abstract*-In a typical WSN network, the sensor collects the information and sends to the network coordinator for further processing. Whereas there are certain applications requiring flow of information/data from network coordinator to nodes or end devices. These applications are typically used for controlling of processes in remote harsh environments. In such types of networks, the nodes are in idle state most of the time. Any communication within the network is initiated only by the network coordinator. The nodes are generally battery powered and energy conservation by adapting various techniques such as Sleep/Wakeup protocols, MAC protocols and data reduction becomes necessary to prolong operational lifetime.**

Paper presents simulation results of star network with 29 end devices and coordinator modeled in OMNeT++. End device implements the energy efficient B-MAC protocol and Modified BMAC protocol for energy conservation. End devices are in asynchronous Sleep/Wake cycle to conserve the energy. End devices wakeup and check for data for duration called check interval (CI) and return to sleep for duration called sleep interval (SI). The coordinator communicates the information/data in broadcast mode. The performance of BMAC and modified-BMAC is compared and results of network throughput, lifetime of end devices for various CI and SI durations are presented.

Keywords: Check Interval [CI], Sleep Interval [SI], Coordinator, End devices, MAC, B-MAC, Lifetime

I. INTRODUCTION

Node of WSN is expected to be battery equipped, and changing or recharging the battery is usually very difficult due to cost constraint and deployment in harsh and remote environment conditions. Therefore, energy efficient techniques are essential for prolonging the lifetime of the end device/node. Wireless sensor network lifetime is a more critical performance metric than others such as throughput and latency adopted for traditional networks [1]. Conserving battery power is a critical issue for WSN in order to maximize its lifetime, currently researchers have been focusing on the development of power saving schemes. They include power saving hardware and topology design, power efficient medium access control (MAC) layer protocol, network layer routing protocol, and so forth. Communication in WSNs can be divided into several layers, where one of them is MAC layer. According to a survey on WSN major source of energy waste at MAC are idle listening, Collision, Overhearing, Control packet overhead and Over-emitting. Considering the above mentioned facts, a correctly designed protocol must be considered to prevent these energy wastes [2] [3]. Among the reason mentioned above idle listening is a major cause of energy waste. There are four techniques to avoid idle listening – static scheduling, dynamic sleep scheduling, preamble sampling and off-line scheduling [4]. Energy efficient communication protocol is a primary design goal for WSN. Many efforts have been done to save energy by MAC with duty cycle, Energy aware routing protocol, data aggregation schemes [5]. Duty cycling is mainly focused on the network subsystem. The most effective energy-conserving operation is putting the radio transceiver in the sleep. End device alternates between active and sleep period depending on network activity. Several MAC protocols using duty cycling mechanism is considered as one of the necessary technique to reduce energy consumption in WSN MAC protocols [6].

Therefore, the MAC protocol for WSN needs to focus on energy efficiency. The results shows throughput of star network and life time of a typical end device for the given battery capacity in various sleep and wake durations is predicted. Network simulation model is developed in OMNeT++ with MiXiM framework. The Contention based energy efficient MAC protocol B-MAC is used for simulation.

II. END DEVICE SIMULATION MODEL IN OMNET++ WITH ENERGY EFFICIENT MAC PROTOCOL

End device based on Host B-MAC is selected from MiXim Framework. The Host B-MAC End device uses SensorApplLayer as application layer, BaseNetw Layer as network layer, B-MAC as MAC layer and PhyLayerBattery as PHY layer [7]. All the layers chosen are MiXim basic classes.

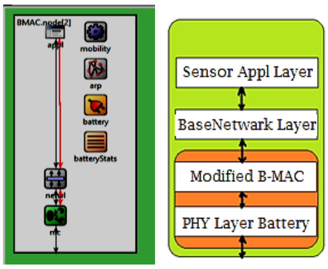


Figure 1: Simulation model of End Device

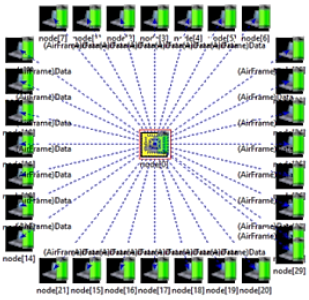


Figure 2: Star network with 29 end devices & Coordinator

Figure 1 shows the layers of a typical WSN end device. For the application layer, a periodic data packet generator is required. SensorApplLayer is a good class for this purpose. While for the network layer, BaseNetwLayer is chosen because end devices are non-mobile and no routing is required in star network, it just propagates the packets to the lower layer. PHY layer manages all radio communication parameters.

A. Star Network Topology

Star network is more suitable for delay critical applications. To form a WSN, twenty nine numbers of end devices are placed in star configuration. The coordinator broadcasts data packets over the medium and end devices receive the packets. End devices are placed within 100 meter distance from coordinator. Coordinator is powered by mains power and End devices are battery powered with specified 130mAHr capacity. Coordinator broadcasts the data packets at periodic interval. Figure 2 shows the star network formation where coordinator is placed at the centre, surrounded by 29 end devices. The B-MAC protocol was presented by J. Polastre in [8] and Anna FÖrster presented the implementation of B-MAC protocol for OMNeT++ and its WSN framework MiXim [9]. In B-MAC protocol, end devices sleep for relatively long duration (in sec) and wakeup at regular intervals (in msec) to check on going communication. The coordinator initiates communication by sending short packets called as preambles exactly for a period of sleep interval. This informs each end device that it needs to wake up to receive data packets. After sending preambles, the coordinator sends out the data packets. After reception of data packets, all end devices go to sleep simultaneously. This overall process is presented in Figure 3. The user can control various parameters of the protocol, such as sleep interval and check interval. Acknowledge packet (ACK) of end devices is disabled in simulation. All the radio parameters like Sleep current, Receive current, Transmit current, switching or ideal current and duration in each operational state are used from previously carried work [10] shown in Table 1.

TABLE 1: END DEVICE RADIO PARAMETERS

Parameter	***Values***
nic.sleepCurrent	0.009mA
nic.rxCurrent	58mA
nic.txCurrent	60mA
nic.setupRxCurrent	8mA
nic.setupTxCurrent	8mA

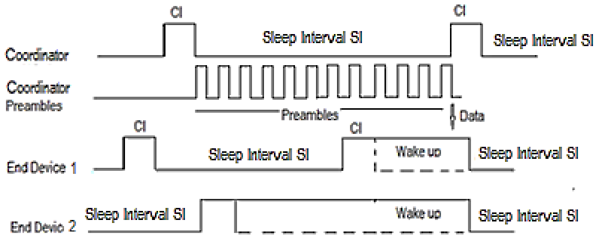


Figure 3: B-MAC protocol

III. PERFORMANCE OF ENERGY EFFICIENT MAC PROTOCOL [B-MAC]

End devices are battery powered having capacity 3.3V, 130mAHr. Through simulation, Minimum Check Interval (CI) for guaranteed data reception is estimated. The CI is a duration for which the end device radio is ON and in listening mode. The coordinator application layer generates data packets every 20 sec [trafficParam]. The data packets generated by application layer are handed over to network layer. The Network layer hands it over to MAC layer and then coordinator broadcasts the data packets in the network. The end device application layer receives the broadcast packets. The Coordinator CI & SI is kept as 0.025 sec & 30 sec respectively in the simulation. The End device CI varies from 0.013 sec to 0.016 sec. The details of simulation parameters are listed in Table 2.

TABLE 2: B-MAC SIMULATION PARAMETERS FOR THROUGHPUT

Parameter	Coordinator	End device
numenddevice	1	29
checkInterval [CI]	0.025 sec	0.013,0.014,0.015,0.016 sec
sleepInterval [SI]	30 sec	30 sec
trafficParam	20 sec	-
nbPackets	1	-

A. Estimation for end device Guaranteed data reception

For confirmed reception of data packet in B-MAC, end devices CI value should be greater than or equal to coordinator CI/2. Figure 4 shows the number of preambles received by each end devices for CI= 0.013, 0.014, 0.015 and 0.016 sec. End device no. 4, 11, and 27 are unable to receive preamble for CI=0.013 sec. This happens because of the coordinator preamble transmission rate. It is confirmed that end devices wakeup asynchronously. End devices data packet reception performance in star network for different CI values is shown in Figure 5.

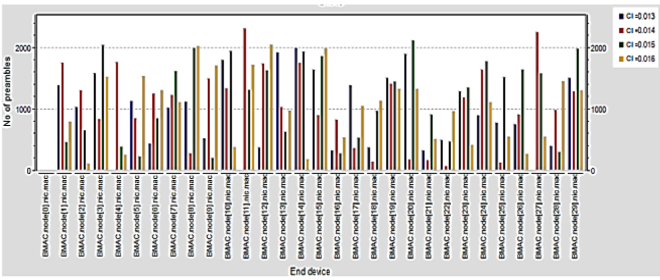


Figure 4: Preambles received by end devices for various CI

Guaranteed data receiving performance of end devices is seen for check interval [CI] 0.014 sec onwards. Therefore for further analysis of network, the check interval [CI] value of each end devices is kept as 0.016 sec considering margins for clock drift.

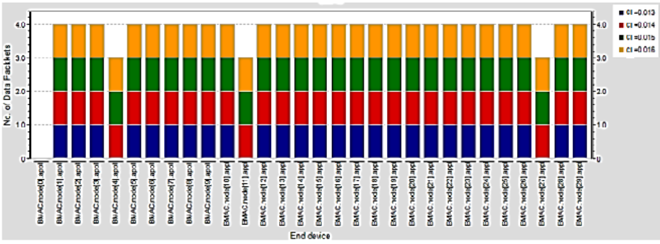


Figure 5: Data packets received by end devices

B. *Lifetime prediction of end device and energy consumption analysis*

TABLE 3: B-MAC SIMULATION PARAMETERS FOR END DEVICE LIFE TIME

Parameter	*Coordinator*	*End device*
numenddevice	1	29
checkInterval [CI]	0.025 sec	0.016 sec
sleepInterval [SI]	10, 20, 30, 40 sec	10, 20, 30, 40 sec
trafficParam	20 sec	-
nbPackets	1	-

Simulation parameters for end device lifetime prediction are shown in table 3. Figure 6 shows the energy consumed by end device for various sleep interval [SI] = 10, 20, 30 and 40 sec. The results of simulations are shown in Figure 7 for SI duration10sec to 40sec and CI 0.016sec for end device. Figure 7(a) shows reductions in consumption of energy in receive state from 89.71% to 71.30%. Figure 7(b) shows as increase in sleep state energy consumption from 9.29% to 27.95%. Figure 7(c) shows that with an increase in sleep interval, energy consumption in switching state decreases from 0.99% to 0.74%. Figure 7(d), (e) and (f) shows the end device % lifetime duration in receive, sleep and switching states.

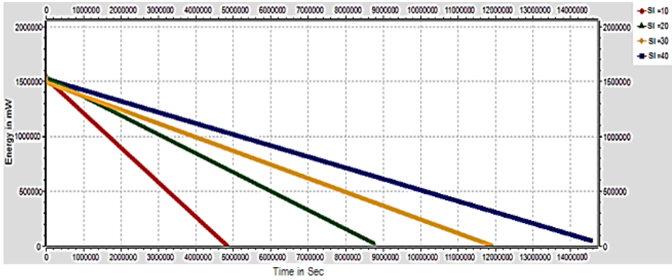
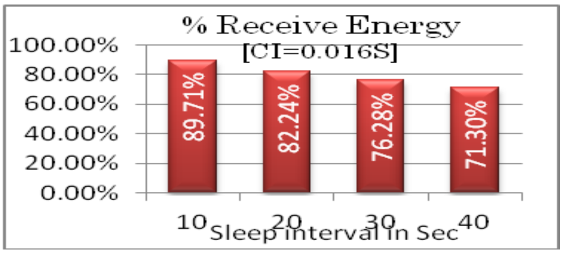
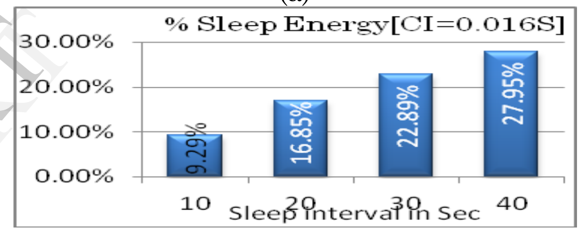


Figure 6: End devices life time prediction for SI=10, 20, 30 and 40 sec

Figure 7(g) shows lifetime of end device for 130mAHr battery capacity. Lifetime of end device increases from 56 to 168 days as sleep interval increases from 10 sec to 40 sec for fixed CI of 0.016 sec.



(a)



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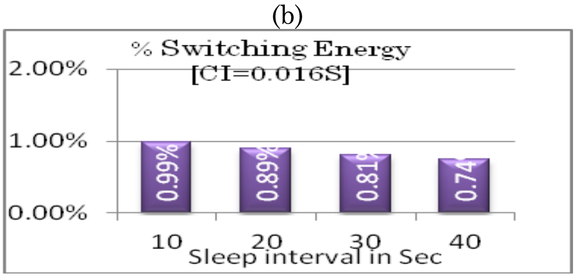

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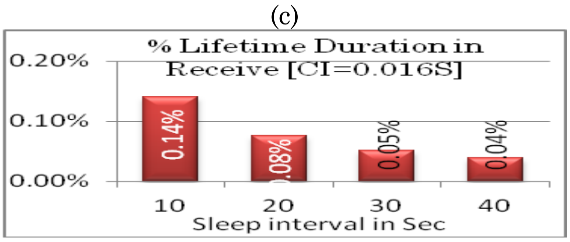

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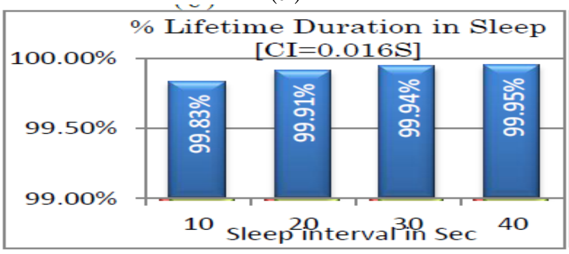

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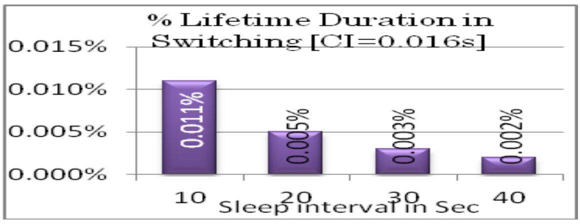

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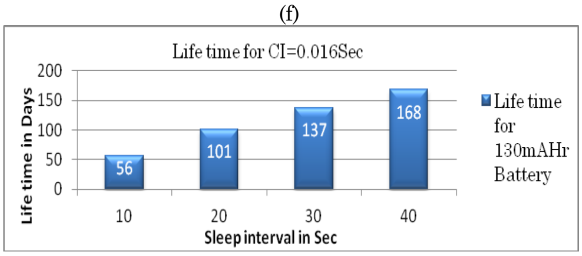

(g)

Figure 7: Simulation results B-MAC energy consumption and life time duration of end device

C. Effect of frequently data packet reception on end device lifetime

TABLE 4: B-MAC SIMULATION PARAMETERS FOR FREQUENTLY DATA PACKET RECEPTION

Parameter	***Coordinator***	***End device***
numenddevice	1	29
checkInterval [CI]	0.025 sec	0.016 sec
sleepInterval [SI]	10,20,30,40 sec	10,20,30,40 sec
trafficParam [TRR]	Every 60 sec , 1 Hrs	-

Lifetime prediction of end device for variable sleep interval was done assuming a single data packet reception during entire life time. Considering practical requirements for frequently broadcast the settings for every 60 sec and 1hrs the performance of end device needs to be verified. End device lifetime prediction for frequently reception of data packets simulation parameters are shown in table 4. Simulation was carried out for coordinator broadcast data packet at every 60 sec (TRR). Figure 8 shows the end device energy consumption for sleep interval 10,20,30,40 sec and CI 0.016sec. The results shows as the sleep interval increases for 10 sec to 40 sec the end device life time was reduced from 13.7 Hrs. to 6.71 Hrs. In B-MAC protocol the preamble transmission duration is exactly same as sleep interval so as increased in sleep interval for 10 sec to 40 sec the energy waste in preamble also increased which reduces the lifetime of end device. Result also shows for SI 30 and 40 sec the life time of end device almost same 6.81 Hrs. and 6.71 Hrs. because of non-proper data communication inside network. To communicate data inside network (TRR-SI)/SI>1 condition should meet. For SI 40 sec (60-40)/40=0.5<1 condition fails. TRR 60sec and SI 40 sec data packets are not communicated as per rate defined. The results show the maximum sleep interval duration is deepens on TRR.

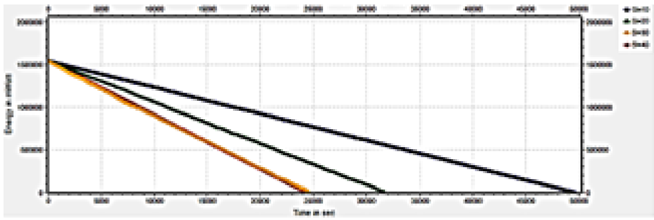

Figure 8: End device lifetime prediction for every 60 sec data setting in network

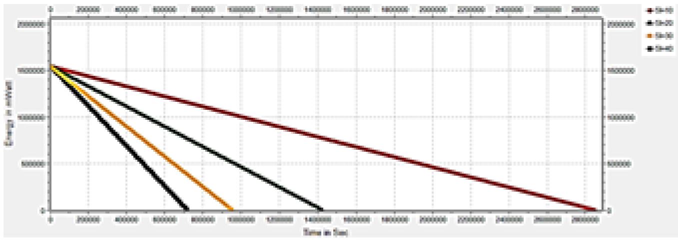

Figure 9: End device lifetime prediction for every 1Hrs. data setting in network

Figure 9 shows the end device energy consumption for sleep interval 10,20,30,40 sec and CI 0.016sec for coordinator broadcast data packet at every 1Hrs. The results shows as the sleep interval increases for 10 sec to 40 sec the end device life time was reduced from 65.9 Hrs. to 16.6 Hrs. End devices receives 792, 396, 265 and 199 data packets respectively during entire lifetime of network for SI 10,20,30,40 sec respectively. The result also shows the life time of end devices is affected by the number of data receiving attempts inside network. If end device having Energy capacity of 130mAHr only single attempt of receiving parameter gives 168 days of lifetime for SI=40 Sec. It was concluded through the above work that B-MAC protocol consumes more energy in preambles. So the modified B-MAC was developed by blocking the preambles communication activity in BMAC to improve the energy efficiency of end device. Recently beacon less strategies have emerged as new direction to improve considerably the WSN Lifetime [4].

IV. PERFORMANCE OF MODIFIED B-MAC PROTOCOL

The B-MAC protocol is modified to reduce the energy consumption in preambles before every data packet. When end device powers on, first initializes the hardware and goes to sleep state. End device wakes up by self-message at predetermined timing interval and checks for clear channel assessment (CCA) and waits for data packet from coordinator and then goes back to sleep state. Self-message triggering events in OMNeT++ for end devices depends on CI, SI and Battery log intervals, whereas for coordinator it will also depend on Application layer data traffic. In coordinator, data packets generated by application layer are put in MAC queue for transmission. Coordinator wakes up for CI duration to check CCA and after completion if it found clear channel than immediately broadcast data packets and then goes to sleep for SI duration.

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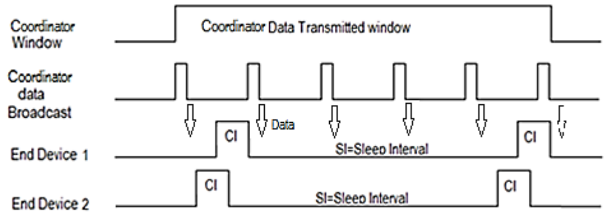

Figure 10: Modified B-MAC protocol

Figure 10 shows the operation of Modified B-MAC with coordinator and two end devices. coordinator application layer generate data packets every 0.014 sec, Data packet broadcasts over medium after completion of CI duration 0.002 sec and goes back to sleep state for SI durations 0.004sec. Coordinator transmits data packet during data transmission window duration. The duration of data transmission window is selected such that at least two wakeup intervals of end device are covered for guaranteed data reception.
Data transmission window duration of coordinator depends on product of application layer traffic rate and number of data packets to be transmitted. Data transmission window in Sec= 0.014 sec * 2900 = 40.6 sec for SI 40 sec. We can vary the coordinator data transmission window by varying the number of data packets to be transmitted. End devices CI varies 0.013 sec to 0.016 sec at step size 0.001 sec by keeping SI duration 20 sec to monitoring network data packet receive performance of end devices. The simulation parameters of End device are shown in Table 5.

TABLE 5: MODIFIED B-MAC SIMULATION PARAMETERS

Parameter	***Coordinator***	***End device***
numenddevice	1	29
checkInterval [CI]	0.002 sec	0.013,0.014,0.015,0.016 sec
sleepInterval [SI]	0.004 sec	20 sec

A. Estimation for end device Guaranteed data reception

Coordinator CI=0.002sec and Traffic rate=0.014sec where end device CI=0.013sec and SI=20sec. Figure 11 shows the no. of data packet received by end devices for CI= 0.013, 0.014, 0.015 and 0.016 Sec. It is confirmed from the graph that for CI 0.013, 0.014 and 0.015 sec single data packets received by no's of end devices 3, 3 and 5 respectively. Only for end devices CI 0.016 sec received data packet twice as per requirement. This happens due to narrow wakeup window size CI of end devices. It was observed during simulation that the minimum CI duration for end devices should be more than Traffic rate of coordinator. The minimum CI duration of end device affects the throughput performance so minimum limit for end device CI duration is depend on coordinator traffic rate interval

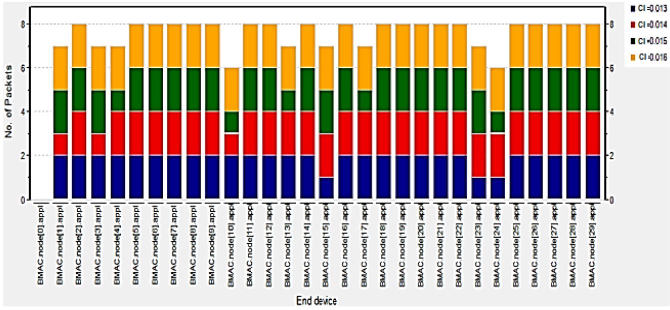

Figure 11: Data packet received for various CI.

B. Lifetime prediction of end device and energy consumption analysis

Simulation parameters for end device lifetime for CI 0.016 sec with various SI are shown in Table 6.

TABLE 6: MODIFIED B-MAC SIMULATION PARAMETERS FOR END DEVICE LIFE TIME

Parameter	***Coordinator***	***End device***
numenddevice	1	29
checkInterval [CI]	0.002 sec	0.016 sec
sleepInterval [SI]	0.004 sec	10, 20, 30, 40 sec

The figure 12 shows the energy consumed by end device for sleep interval [SI] 10, 20, 30 and 40 sec. The results of simulations are shown in figure 13 for sleep interval SI 10 sec to 40 sec and CI 0.016 sec. Figure 13(a) shows reductions in consumption of energy in receive state from 89.59% to 69.90%. Figure 13(b) shows as increase in sleep interval consumption of energy is also increase in sleep state from 9.39% to 29.31%. Figure 13(c) shows as increase in sleep interval number of switching attempts are reduced so energy consumption in switching state decreases from 1.00% to 0.78%. Figure 13(d), (e) and (f) shows the end device % lifetime duration in sleep, receive and switching states. Figure 13(g) shows lifetime of end device for 130mAHr and 3800mAHr battery capacity, Lifetime of end device varies from 56 to 176 days and 4.5 years to 14.13 years respectively as sleep interval varies from 10 sec to 40 sec for wakeup [CI] 0.016 sec.

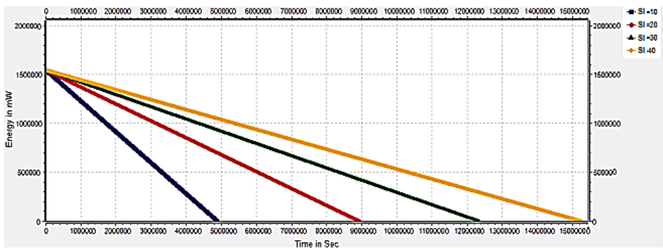

Figure 12: End devices life time prediction for SI=10, 20, 30 and 40 sec

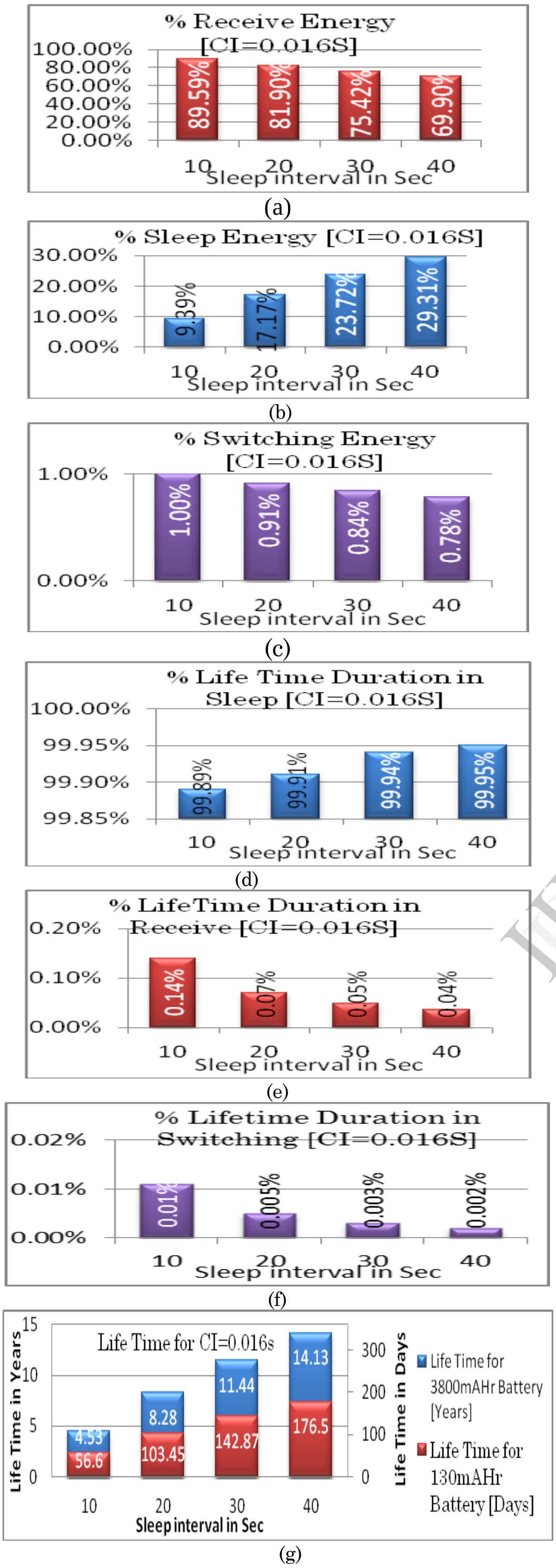

Figure 13: Simulation results modified BMAC energy consumption and life time duration of end device

Whereas 167 days lifetime is predict by Maxstream calculator for SI 40 sec and 176 days from OMNeT++ simulation for 130mAHr battery capacity.

V. Conclusion

The performance of low power contention based energy efficient B-MAC protocol is evaluated for star configured network consisting of 29 end devices & a coordinator using OMNeT++ simulator. The simulation result shows that end device lifetime for 130mAHr battery capacity with single data packet communication increases from 56 days to 168 days as sleep interval (SI) is increased from 10sec to 40sec.

In real life applications the data communication is more frequent; therefore the modeled network is further evaluated for data packets communication at repetitive intervals. For data communications at every 60 seconds interval, the simulation result shows for the same battery capacity and sleep interval (SI) of 10 sec reduction in lifetime from 56 days to 13.7 hours. If sleep interval is increased to 40 sec keeping other parameters unchanged, the lifetime further reduces to 6.71 hours. In B-MAC protocol, the coordinator sends preambles to keep the node awake for exactly the same period of time as the sleeping period. Thus, every node will wake up and receive a preamble. The radio of end device is in 'listen' state for this entire 'preamble' duration. Substantial amount of energy is consumed repetitively during each data communication.

If the data communication interval is increased to one hour, the lifetime is estimated as 65.9 hours & 16.6 hours for Sleep Interval of 10 sec & 40 sec respectively.

Specific WSN applications used to control of different processes in remote harsh environments, the flow of information/data is always from network coordinator to end devices. In such types of networks, the nodes are in idle state most of the time. Implementation of B-MAC, in such type of schemes is not desirable considering the energy wastage during preambles for each data communication. Therefore, modified B-MAC protocol is proposed for these types of application requirements, by blocking 'preambles'. The protocol uses duty cycle approach for lifetime improvement. The simulation was carried out on similar network with proposed modified B-MAC protocol. The simulation result shows that end device lifetime for 130mAHr battery capacity with single data packet communication increases from 56.6 days to 176.5 days as sleep interval (SI) is increased from 10sec to 40sec. These results are comparable with the B-MAC implementation for single data packet communication. The end device lifetime is independent of the no of times data communication takes place in the network. The lifetime remains constant for the given sleep interval. End device with proposed scheme and with CI=0.016s and SI=40sec can operate for 14.13 years with lithium battery of capacity 3800mAh (ER18505).Through the study, it is concluded that the operational lifetime of several years is achievable with commercially off-the-shelf available batteries.

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