Energy Efficient MAC Protocol for Broadcasting in Asynchronous Low Duty Cycle Wireless Sensor Networks

Appurve Chaudhary
Student, Bhagwant Institute Technology, Muzaffarnagar, Uttar Pradesh, India

Prof. (Dr.) Lokesh Kumar Bansal
Professor, Bhagwant Institute Technology, Muzaffarnagar, Uttar Pradesh,India

Ajay Singh
Assistant Professor, Bhagwant Institute Technology, Muzaffarnagar, Uttar Pradesh,India

Abstract

Synchronizing data communication between nodes with energy efficiency by adapting different low duty cycling mechanisms is the most important task of the Medium Access Control Protocol (MAC) in Wireless Sensor Networks (WSN). Most of the low duty cycle MAC protocols address the issue of unicast efficiently, ignoring the broadcast performance which presents significant challenges due to the duty cycling.
In this paper we propose first the work, an asynchronous low duty cycle MAC protocol for broadcasts in WSN that would incorporate the advantages of existing sender initiated and receiver-initiated MAC protocols. The Preamble based Receiver-Initiated Broadcast MAC (PRIB-MAC) protocol is built on RIMAC (Receiver Initiated MAC), a unicast MAC protocol by adding a preamble to support broadcasting. It is found that the duration of the preamble depends on the time difference in the wake-up schedule of the nodes and with an optimized wake-up schedule the preamble duration of just 2% of the slot duration can give 100% node coverage in a very less time compared to Asynchronous Duty-cycle Broadcasting (ADB): an efficient multihop broadcast protocol based on asynchronous duty cycling in WSN.
In this paper we propose the second work, the Preamble based Receiver-Initiated Broadcast Connected Dominating Set (PRIB-CDS) is built on top of PRIB-MAC with the addition of dynamic forwarding technique by forming a forwarding set with the help of the Greedy algorithm. The simulation results of the proposed PRIB-CDS algorithm shows that it has reduced the number of transmissions significantly as it reduces forwarding nodes and balances the energy between the nodes to avoid re-broadcasting the data. Self-organizing multi-hop networks necessitate the broadcast of the data for data dissemination, generally achieved by flooding methods that suffer from issues like retransmission, contention and collisions. The second work PRIB-CDS solved some of these issues but had scope for improvement in reducing contention.

1. Introduction

1.1 WIRELESS SENSOR NETWORKS

Wireless Sensor Network (WSN) is the most sought technology for commercial and industrial applications. The WSN architecture built using a collection of nodes is used to detect environmental conditions like temperature, pressure, humidity, position, vibration, sound, etc. At present, these nodes are used in numerous real-time applications to execute different functions like data collection, data processing, data storage, target tracking, target detecting, target monitoring, target control, synchronization, node localization, and effective routing between base stations and nodes.
WSN is one type of wireless network, which contains a collection of geographically circulated self-organized, and low-powered devices called sensor nodes or motes, which exactly cover a large number of distributed,

small, battery-operated, embedded devices that are connected within a network to collect, process and transfer the data to the Base Station(BS). Each node consists of parts like a transceiver for communication between them, battery, microcontroller, and memory, where they act like small computers that are interconnected together to form a network.

1.2 ELEMENTS OF WSN

The WSN contains two elements like sensor nose and network architecture. Sensor nodes contain sensing, computing, communication, actuation, and power components interconnected as single or multiple boards, enclosed as a cubic inch. Sensors gather the analogue data from the physical environment, and Analog to Digital Converter (ADC) converts this data into digital data. Sensors also contain additional features like processions, communication and storage and are responsible for network analysis, data correlations, and the fusion of data.
The network architecture in WSN based on the Open System Interconnection (OSI) reference model contains five layers like an application layer, transport layer, network layer, data link layer, and physical layer. On combining these five layers, cross-layers are formed which consist of three layers. The three cross layers are the power management plane, mobility management plane, and task management plane.

2. PRIB-MAC: A Preamble based Receiver Initiated MAC Protocol for Broadcast in WSN

MAC protocol is a key factor to improve the battery lifetime, throughput, latency, and QoS through better utilization of the medium in WSN. The MAC protocols designed for conventional networks are less energy efficient due to ideal listening, collision, overhearing and protocol overhead. The MAC protocols for WSN adopt low duty cycling to achieve energy efficiency and can be broadly classified into synchronous and asynchronous duty cycle protocols.
The synchronous duty cycle protocols require adjusting the schedules with neighbors. It reduces the latency time but requires a synching mechanism at each node which increases energy consumption. The nodes in asynchronous duty cycle protocols wake up based on their own schedule and several mechanisms are proposed for coordination of source and receivers to complete the transmission of data. Sender-initiated MAC protocols follow a mechanism where the sender node sends a long preamble that is sufficient to be received by the receiving nodes before sending the data. Though it is efficient in establishing coordination, it causes interference with the non-participating nodes and thereby reduces channel utilization.
Another mechanism is the receiver-initiated MAC protocols where the sender node waits for a signal from the receiving node before sending the data and this replaces the long preamble with beacons from the receiver node which significantly improves network utilization and throughput.

Algorithm of PRIB-MAC Protocol

```
1: check channel
 2: if the channel is free and data to send then
 3: switch to Tx mode
4: wait for the beacon
5: if s receive a beacon from r(n) then
 6: do
7: s send a preamble to r(n)
 8: wait for tint
                9: until timeout
 10: end if
11: s broadcast the data packet
12: else
13: switch to Rx mode
 14: if preamble received from n then
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15: wait for data from n after the preamble.
16: end if
17: end If
18: go to sleep mode

Simulation Methodology

PRIB-MAC protocol is evaluated using Mixed Simulator (MiXiM) which works on OMNeT++ simulation engine. PRIB-MAC is added to the MAC layer of the MiXiM as described in the algorithm in the implementation section. The simulation parameters used for the simulations are tabulated in table 3.1. Then assumed symmetric links and zero propagation delay for the purpose of simulations. The simulation results of the PRIB-MAC protocol is compared with ADB, another RI-MAC based broadcasting scheme for Asynchronous Duty Cycle Networks.

Table Simulation parameters

Parameter Value

Simulation Area 300m
No. of Nodes 6 to 21
Queue length 2
Header length 24 bits
Bitrate15360 bps
Check Interval0.01s
Slot Duration 1s
Default Dwell Time 0.3s
Analogue Model Simple Path loss Model
SNR Threshold 0.12589254117942
Busy Threshold 3.98107170553E-9

Simulation Results

Network coverage percentage (%) Preamble duration (Sec.) Non-Optimization Optimization

0.002 25% 71%
0.02 65% 100%

With a shorter preamble (0.002 s), lesser nodes woke up during the preamble duration and only those nodes received broadcast data to flood down and hence the coverage is only 71%
But when the preamble duration is kept longer (0.02 s), more nodes woke up in the preamble, improving the coverage to 100%

3. PRIB-CDS: An energy-efficient low duty cycle broadcasting scheme for WSN

To meet the energy efficiency requirements, WSN employs various asynchronous low duty cycling techniques, where the nodes sleep and wake up on their own schedules to conserve energy and several sender-initiated and receiver-initiated mechanisms are proposed to achieve coordination among the nodes. But these techniques perform poorly for broadcast traffic, as the broadcasting techniques like repeated unicast proposed in ADB and flooding lead to redundancy, increased latency and energy consumption. Therefore, providing a solution for energy-efficient broadcasting in low dutycycled networks is an important issue in WSN, which we have tried to address in the first work PRIB-MAC. As an alternative to repeated unicast for broadcasting, it employed short preambles as part of the receiver-initiated low duty cycle mechanism. The results were promising with improved network coverage and reduced control overhead and energy consumption. However, re-transmission is a common issue in these low duty cycle based protocols which can be effectively reduced by using dynamic forwarding techniques. In dynamic forwarding, the forwarder node is elected by using any one of the mechanisms such as Cluster-based, On-demand or Multiple Criteria based, CDS based, etc.

Network Model

Let us consider there are n nodes in the network, which are equally distributed in an equal transmission range of one unit. The given network is defined as a graph G(V, E) in which V is the set of nodes and E is the edge where an edge is represented as {u,v}E where u and v are the nodes within the communication range. G represents a non-unit disk graph.
Let N(v) is a neighbor set of node v (including v) then N(V)=UnionVN(v) is a set of all nodes of V and V covers U if U N(V).
A fractional x-hop detail of a node v is a sub graph Gx(v)=(Nx(v),Ex(v)) of the network G. Here Nx(v) is the x-hop neighbor set and Ex(v) is the x-hop connection set of v. Now we can specify N0(v), Nx(v), and Ex(v) as in the equations (1.1), (1.2), and (1.3).
N 0(v) ={v} and (1.1)
Nx(v)= U uNx-1(v)N(u) for $x \geq 1$ and (1.2)
Ex(v) ={(u, w) ǀ u Nx-1(v) w N x(v)} (1.3)
It includes links among the nodes in Nx(v). But excludes the link between two nodes which will be precisely x hops from v. Gx(v) collected from v by sending x rounds of the “Hello” packet. It is shown in figure 4.1 and if v has 1-hop neighbor details, then it knows all its neighbors but not the link between these neighbors. The entire x-hop detail of a node v is a subgraph that is given in the equations (1.4) and (1.5).
G ǀ x(v)=(N x(v),E ǀ x(v)) (1.4)
Where E ǀ x(v)={(u,w) ǀ u, w N x(v)} (1.5)
It is the entire x-hop connection set of v and that details are collected by sending (x+1) rounds of the “Hello” packet. We assume each node asynchronously assigns its own sleeping schedule and can transmit the data when it wakes up but receives the data only during its active time slots.

Protocol implementation

Greedy algorithm for calculating forwarding set F(G)

1: If a node is in H2(G) and if it is covered only by u
then add u H1(G) to F(G).
2: Check the uncovered node in F (G). (If a node in H2(G) is not covered by F(G) then it is called an uncovered node).
3: If u envelops highest no. of uncovered nodes in H 2(G) then add u H1(G) to F(G).

The above greedy algorithm is used to calculate the forwarding set F(G). The selection of F(G) From that N(v) is covered when v transmits. Therefore H2(v) is defined in equation.
H2(v)=(N2(v)-N(v))
It is used instead of N2(v). The neighbor u is important because a node in H2(v) is only covered by u. The above algorithm 4.3.3, first covers the required neighbors and then neighbors with higher degree nodes are selected to cover H2(v). If two neighbors are in the same degree, any one of the nodes is selected to form a forwarding set F(G). This can be identified by selecting the node with the minimum number of connected nodes.

Table Forward list creation process

Previous Node(u) Current Node(v) H1(v) H2(v) FWRD_SET

Null A {B, C, D, E} {I, J, K, L, M} {B, D, E}
A B {I, J} {K, L, M} {I, J}
B C {J, K} {L, M} {J, K}
C D {E, K} {L, M} {E, K}
D E {D, L, M} {I, J, K) {D, L, M}

Broadcasting Algorithm of PRIB-CDS

1: Based on the ID and data SEQ If the data is received for the first time then
2: If the channel is free and data to send then
3: Switch to Tx mode and wait for the beacon
4: Let FRWD_SET be the set of nodes in F(G) except the source node S If u FRWD_SET and receive a beacon from u then 5: send a preamble time (wait for tin) to u Until time out and the data broadcasting occurs.
6: end if
7: end if
8: end if
9: go to sleep mode

Result and discussion

The performance of PRIB-CDS is evaluated for some of the key parameters in broadcasting such as the number of transmissions, network coverage and energy efficiency. The results are compared against our previous work PRIB-MAC upon which PRIB-CDS is built on and some of the state broadcasting protocols in WSN such as ADB, a RI-MAC based asynchronous duty-cycled protocol and SALB, an asynchronous CDS based local broadcasting protocol for WSN.

4. Conclusion and future enhancement

In the quest for building an efficient and robust MAC protocol for broadcasting applications in asynchronous duty cycle wireless sensor networks, the proposed PRIB-MAC leverages the advantages of both sender and receiver-initiated MAC protocols by employing short preambles. The evaluations of this protocol reveal the relationship between the wakeup schedule of the nodes and the preamble duration and successfully established the preamble duration for efficient broadcasting. With an optimized wake-up schedule, the preamble duration of just 2% of the slot duration can give 100% node coverage in very little time. And the evaluation of this preamble based approach against the multiple unicast approaches proposed in ADB shows significant improvement in network coverage time and average energy consumption of the nodes.
The simulation result of the proposed work shows that compared with PRIB-MAC, the proposed PRIB-CACDS is better in terms of reducing retransmission, energy consumption and achieving network coverage within 2.4s. Finally, a hybrid CDS based approach is implemented in the PRIB-HCDS algorithm, which is constructed by combining the advantages of PRIB-CDS and PRIB-CACDS. Its broadcast performance is compared with the other state-of-art asynchronous low duty cycle broadcasting schemes like SALB and ADB, which proves its better results in reducing retransmission and it consumes only (3.4%) of energy for 500 node networks.
In future, this can be implemented in various broadcasting scenarios for low duty cycle WSN based applications such as remote patient monitoring systems, agricultural applications, forest fire detection and IoT applications, etc., with real motes.

References

1. AbdelkaderKhelil,&RachidBeghdad. (May 2015). Distributed Algorithm for Coverage and Connectivity in Wireless Sensor Networks. 5th International Conference on Computer Science and Its Applications (CIIA), Saida, Algeria, pp.442-453.
2. AbirHossain, Mahfuz Reza, Nafiul Bari Khan, &TasnimAlam. (2016). IRI-MAC: An Improved Receiver Initiated MAC Protocol for Wireless Sensor Network. International Journal of Computer Applications, 143, pp. 0975–8887.
3. Afia A., Tahrima O., Diana S., &NawrinFerdous, C. (2019). Construction of Connected Dominating Set to reduce contention in Wireless ad hoc networks. Proceeding of the 6 th International conference on networking system and security, pp. 59-67.
4. Amre El-Hoiydi& Jean-Dominique Decotignie. (2004). WiseMAC: An ultra-low-power mac protocol for the multihop wireless sensor networks. In: Nikoletseas S.E., Rolim J.D.P. (eds), Algorithmic Aspects of Wireless Sensor Networks. ALGOSENSORS 2004. Lecture Notes in Computer Science, vol 3121. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-27820-7_4.
5. Arifuzzaman, M. Matsumoto, M. & Sato, T. (2013). An Intelligent Hybrid MAC with Traffic-Differentiation Based QoS for Wireless Sensor Networks. IEEE Sensors Journal, vol. 13(6), pp. 2391–2399.
6. Arun Kumar, Kai-Juan Wong, Ming Zhao, Peter Han Joo Chong, & Yong Liang Guan. (2018). A Comprehensive Study of IoT and WSN MAC Protocols: Research Issues, Challenges and Opportunities. IEEE Access, vol (6), pp. 1-35, DOI:10.1109/ACCESS.2018.2883391. 123
7. AshikurRahman, PawelGburzynski, &BozenaKaminska. (June 2007). Enhanced Dominant Pruning-based Broadcasting in Untrusted Ad-hoc Wireless Networks. In: Proceedings of IEEE International Conference on Communications, ICC, Glasgow, Scotland, UK, pp. 3389–3394.
8. Bajaj, K., Sharma, B., Singh, R. (2020). Integration of WSN with IoT Applications: A Vision, Architecture, and Future Challenges. In: Rani S., Maheswar R., Kanagachidambaresan G., Jayarajan P. (eds) Integration of WSN and IoT for Smart Cities. EAI/Springer Innovations in Communication and Computing. Springer, Cham. https://doi.org/10.1007/978-3-030-38516-3_5..
9. Becker,M., Wenning, B. L., Görg, C., Jedermann, R., &Timm-Giel, A. (2011). Logistic applications with wireless sensor networks. In Proceedings of the 6th Workshop on Hot Topics in Embedded Networked Sensors, Killarney, Ireland, pp.1– 5.
10. Bharghavan, V., & Das, B. (1997). Routing in Ad Hoc Networks Using Minimum Connected Dominating Sets. Proceeding of International Conference on Communications ICC'97, vol (1), pp. 376-380. DOI: 10.1109/ICC.1997.605303.
11. Bokareva, T., Hu, W., Kanhere, S., Ristic, B., Gordon, N., Bessell, T., &Jha, S. October (2006). Wireless sensor networks for battlefield surveillance. In Proceedings of the Land Warfare Conference, Brisbane, Australia, pp. 1–8.
12. BrijeshKundaliya. (2020). Challenges of WSNs in IoT. IntechOpen, DOI: 10.5772/intechopen.95352. Available from: https://www.intechopen.com/onlinefirst/challenges-of-wsns-in-iot.