A Critical Review on Energy-Efficient Medium Access Control for Wireless and Mobile Sensor Networks

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***Abstract*—Wireless sensor network (WSN) has garnered remarkable attention due to its wide supports for plenty of applications such as, health systems; military based applications, environmental monitoring, and tactical system. In Contention-Based Medium Access Control (MAC) protocols related to the energy consumption. In this paper, a combative review of energy consumption in Contention-Based MAC protocols was provided. Furthermore, a general comparison that stated the strengths and drawbacks with every utilized technique was offered. The main aim of this paper is to assist the researcher to choose the right protocol for developing purpose or further investigation regarding the performance.**

***Index Terms*—Wireless Sensor Network; Energy Efficiency; Mobility; Contention-Based MAC Protocol; Packet Scheduling.**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have received a remarkable attention lately, due to the huge reliance of multifarious applications on wireless sensor networks such as disaster management [1], environment monitoring [2], climate control [3], medical systems [4], robotic exploration [5], and target tracking [6-9]. However, the primary limitation for node sensor is the low power support, which makes energy efficiency as the core of the problem [10]. The energy waste occurs due to the communication module. To address the communication modules medium access control is strictly embedded with WSN due to the importance effect on node's energy consumption [11]. Moreover, collision, overhearing, idle listening and control packet overhead considered as major source of energy inefficiency [12, 13]. Therefore, to address those issues, different types of Medium Access Control (MAC) protocol have been proposed to improve the energy consumptions and increase node's lifetime such as Time Division Multiple Access (TDMA). This paper explores more options and concerning on Sensor-MAC (S-MAC) protocol, particularly, on the typical MAC protocols in recent years from four prospective, contention based, scheduling based, and hybrid and cross layer.

II. CONTENTION-BASED MAC PROTOCOL

The aim of MAC Protocols is to control the access of shared wireless channel medium, in order to satisfy the underlying applications. Several studies were conducted on developing MAC protocols. MAC Protocols are categorized in three different categories: contention-based, schedule based, hybrid and cross layer protocols [14, 15]. Contention based protocols are based on Carrier Sense Multiple Access (CSMA). This approach based on sensing the shared medium before transmitting the data. In general contention-based protocols aim to avoid the collision in the shared medium access to save more energy and reduce the latency. In this section, we will review some of the most widely contention based protocols [16, 17]

A. *Sensor-MAC and Mobility Sensor-MAC (S-MAC & MS-MAC)*

S-MAC is a contention-based protocol. S-MAC has two periods. The first period is called the sleep (idle) period and the second one is active (wake up/ listen) period [18]. In the active mode (listen), the node turns on its radio and starts transmitting the Synchronous (SYNC), Request to Send (RTS), Clear to Send (CTS), Data and (Acknowledge) ACK packets. Whereas in the idle mode, the node turns off the radio and sets a time to wake up for the next period. A Significant amount of energy will be consumed during the active mode, the issue occurred when if there are no packets to transmit during this cycle, the energy will be wasted and that will increase the latency and decrease the throughput [19]. Figure 1 shows the time frame for S-MAC.

Figure 1: S-MAC Two Phases [18]

S-MAC was extended to MS-MAC. MS-MAC supports the mobility features for the nodes [20]. This protocol based on two period duty cycle (listen and sleep). MS-MAC is a synchronous protocol, like S-MAC. In case that the mobility is detected in the cluster, the topology can be changed due to the movement of the node; S-MAC cannot handle this situation. MS-MAC is able to perform well based on RSSI values. MS-MAC gets RSSI values from SYNC control messages. In the cluster, each node knows the RSSI value for its neighbor [21]. If RSSI value changes during interval time, which means even the neighbor node is moving, or there are two nodes moving. Based on RSSI values, the speed of the movement can be predicted.

The mobility node transmits its new control messages and the maximum speed estimation. The other nodes update their SYNC information regarding the mobile node, in case the node intends to leave the network cluster. The relation between the speed of the node and the SYNC frequency is proportional relationship, whereas when the moving node speed increase, the SYNC frequency increases. To make the set up for the connection with the new cluster network, the mobile node has to be active as much as possible, because if it goes to sleep, the SYNC information has to be updated again, and it will lose the new neighbors. In case that the node is moving, but still within the border of the cluster (the node is not leaving the cluster), the mobility field in the SYNC information will be set as empty.

B. Timeout-MAC (T-MAC)

T-MAC avoids the defects of S-MAC. T-MAC considers as an upgraded version of S-MAC. S-MAC has a static cycle (the period time is fixed), whereas T-MAC has dynamic cycle, and that will reduce the wasting energy in active mode [22].

T-MAC uses variable length bursts to perform the data transmission, in case there is nothing to transmit, the node will go the sleep mode as showed in Figure 2. T-MAC uses interval of time parameter $T(a)$ to determine when it will switch to the sleep mode. If the node waited for a time (t), which is greater than $T(a)$, the node goes to sleep mode. Thus, T-MAC solves the wasting energy in active (listening) mode. Figure 2 shows the T-MAC cycle [22]. Due to this approach, T-MAC suffers from early sleep problem. This problem was fixed in T-MAC by using future RTS (FRTS).

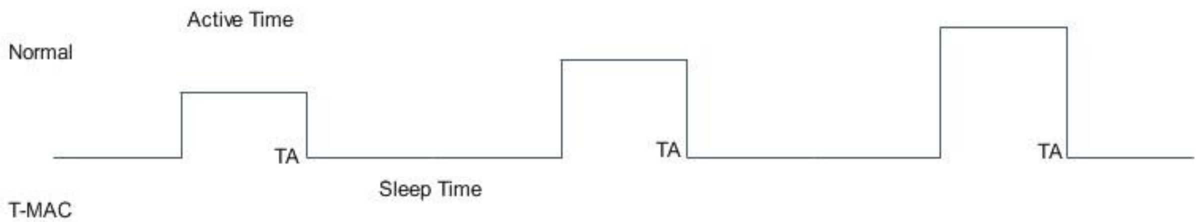

Figure 2: T-MAC Working Scheme [22]

C. Berkeley MAC (B-MAC)

B-MAC does not use RTS, CTS, ACK packets (no overhead). B-MAC, which is a contention based protocol, uses smart (adaptive) preamble sampling approach in order to minimize the idle listing time [23]. The preamble time is a little bit longer than the sleep time in the receiving node. Consequently, the receiving node will wake up and receive the data after receiving the preamble [24]. In the sender side, if the node wants to send packets, it waits for "a back off" time. Then, the node checks the channel, if the channel is free, the node starts transmitting the packets, if the channel is not free, it waits again for a back off time [23]. B-MAC achieves better results than S-MAC in terms of latency, energy efficiency and throughput, due to control packets are not utilized in this protocol [25].

D. Wise MAC

Wise MAC uses non-persistent CSMA with preamble sampling [26]. Wise MAC employs dynamic approach to compute the length of the preamble. When the traffic is low, Wise MAC reduces the power consumption, whereas if the traffic is high, Wise MAC boosts the energy [25]. Wise MAC has some flaws such as; hidden terminal problem.

E. X-MAC and Mobility Aware-MAC (MA-MAC)

X-MAC is based on Wise MAC.X-MAC has a short-length series of preambles packet size; these preambles include the target address information. Figure 3 shows these preambles [27]. With this approach, the energy consumption will be improved [27]. To achieve this aim, X-MAC needs accurate clock synchronization. In addition, X-MAC uses handshake approach, in order to reduce the latency and increase the energy efficiency [28]. The main difference between X-MAC and Wise MAC, that X-MAC uses the short length preambles packets and handshakes approach. Figure 4 illustrates MA-MAC short length preambles approach.

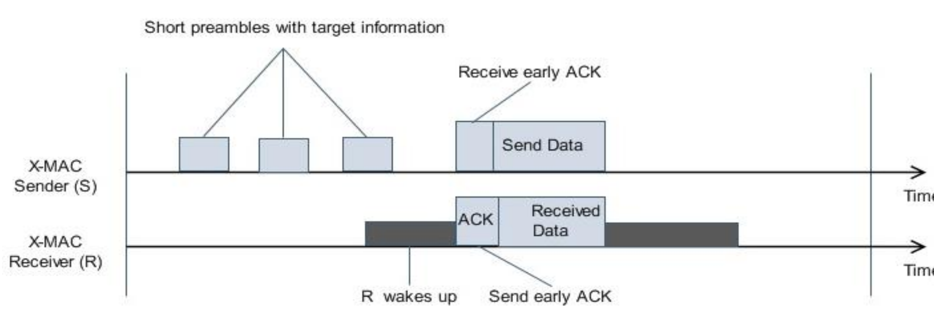

Figure 3: X-MAC approach [28]

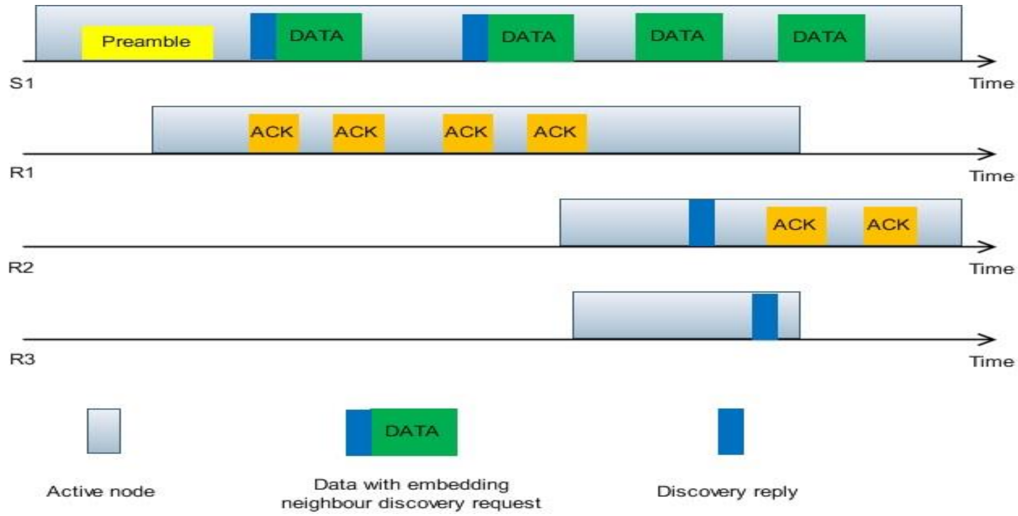

Figure 4: Handover steps in MA-MAC[17]

F. Mobile Awareness (MA-MAC)

Mobile Awareness (MA)-MAC is an extension from X-MAC. MA-MAC [29] works exactly the same like X-MAC if the nodes are fixed. In mobility case, MA-MAC creates a smooth handover; this is achieved by moving the remaining data to the new node before the link is lost. In order to achieve this aim, MA-MAC determines two threshold values regarding the distance between the nodes. The first threshold value asks for smooth handover, the second threshold value determines the maximum distance limit, so when the node exceeds this threshold, the data have to be moved to a new node. The previous procedure occurs when the transmitter detects that first threshold value was exceeded. To create the link and move the maintained data from the old node to the new one, at least one ACK should be received before it goes to the second threshold and starts the handover process. Thus, the moving node is able to discover the new neighbor.

G. Receiver Initiated MAC (RI-MAC)

RI-MAC is asynchronous protocol. In the above-mentioned protocols, the transmission process is based on the sender side. In RI-MAC protocol, the transmission process relies on the receiving node. When the receiver node is active, it broadcasts a beacon signal to the sender, which means that the receiver is ready to get the data, then the sender starts sending the packets. Once the packets are received in the receiver side, another beacon signal will be transmitted. This beacon signal performs two significant roles; the first one means that packets were received successfully, whereas the second one means, that receiver is ready to receive new data [30]. Figure 5 shows the concept of RI-MAC.

H. Predictive Wakeup MAC (PW-MAC)

Predictive wake up MAC protocol is also asynchronous protocol and based on receiver-initiated protocol as well. Significant improvements were implemented in this protocol. The sender side can expect the receiver wake up time period. In addition, a prediction-error correction mechanism is included to avoid the error, if sender miss predicts the wake up time for the receiver due to certain reason such as; hardware and operating system delay. Thus, PW-MAC is very efficient in terms of energy.

The mobility aware TDMA-based MAC protocol is an extension of TDMA time allocation mechanism for adapting mobility fluctuation in mobile wireless sensor network topology [34]. The network in M-TDMA is divided into non-overlapping cluster using FLOC algorithm [35]. Each cluster has its own head, in the same times each node within the cluster is assigned with a unique time for sending and receiving purpose. To solve mobility, issue those slots could be shared across the clusters and some kept for future allocation. M-TDMA splits into control data and data part. The control part used to control mobility whereas node transmitted packet used data part. Figure 5 denotes the control part, which comprises of the first three slots. Cluster information such as ID, head status, cluster schedule and round number will be broadcasted by the head. If node receives this clustered information, directly will understand it is status remaining connected with the original cluster. Therefore, its status will be updated only in the second slot. If the node does not receive any clustered information, it noticed that it is no longer in communication with the original cluster but has not linked to any new clustered and it has to wait till the clustered information received in another round. If the clustered information not received in second round, it is not necessary to wait for long receiver the clustered information to join the network but it could receive the information from other head node which will learned that it has joined another cluster. Once the clustered information successfully received the head node will check for any unsigned slots in the data part. If more than one node not assigned, the head will assign them in the third slot and update the clustered schedule. However, if only one slot is free, the head will split the bandwidth by doubling the period in which the new node transmits and the other half will be kept for future entering nodes. The head will frequently update the schedule by maintaining a sequence of IDs, with the last element serving as a placeholder.

Reducing the overhead and idle listening in the sender's and receiver’s side [31]. Table 1 shows a comparison between the previous protocols in terms of; used technique, strengths and weakness points

Table 1
Comparison between the previous Contentions based protocols

Protocol	Technique	Strength	Weakness
S-MAC	Static period	Simple managing.	Wasted energy during active mode. More latency and fewer throughputs. Control packets overhead.
	Synchronous and RSSI values	The speed of the mobile node can be adapted with synchronous frequency.	Consumes a lot of energy on order to keep the node active to discover new neighbors.
T-MAC	Dynamic Period	Reduce the waiting tine in active mode	Early sleep. Control packets overhead.
B-MAC	Adaptive preamble sampling approach	Free of control packets. Performs better than X-MAC.	Not considering the traffic status in the access medium.
Wise MAC	Short length preambles packets	Considering the traffic status in the access medium.	Hidden terminal problem.
X-MAC	Short length preambles packets and handshakes approach	Less energy consumption and latency than Wise MAC	Not optimal for all traffic types.
MA-MAC	Defining Threshold values	New nodes to transmit the data to; can be discovered during communication time.	Not easy to achieve node handover if the network density is high.
RI-MAC	Receiver-initiated process	Less energy consumption rates than X-MAC.	Random checks for receiver wake up time.
PW-MAC	Receiver-initiated process	Expectation of receiver wake up time A prediction-error correction mechanism	NA

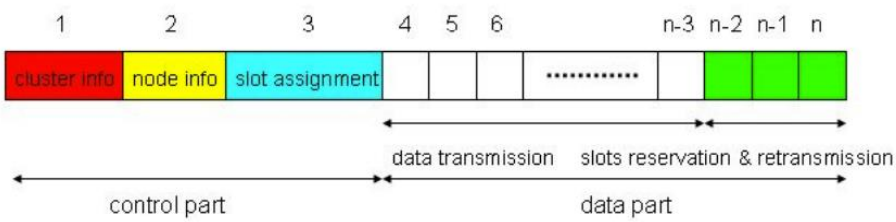

Figure 5: M-TDMA working principle [36]

III. Scheduling Based MAC Protocol

TDMA scheduling-based MAC protocol distinguished over contention-based first, as collision free scheme due to the allocation of a unique time slot to every node to send and receive data, second, interferences between adjustment wirelesses links is avoided. Third, hidden terminal problem without extra messages overhead can be solved. Other types of TDMA-based MAC protocols will be discussed as follows:

A. Mobility-MAC

This mobility adaptive collision free is scheduling based MAC protocol [32]. M-MAC protocol follows the design principle of TRAMA and it is very suitable for wireless sensor environment, as shown in Figure 3. M-MAC introduces a flexible frame time that able to adapt mobility issues. The time is divided into plenty of rounds and each round comprises of K frames. At first, the entire nodes in the network knows the mobility states based on AR-1 mobility estimation model [33]. The average of theses node's location estimated is considered as location prediction for next frame. The information will be sent to the clustered head, which never goes into sleeping mode, which leverage it to collect the values from its members and broadcast them in the last slot of the frame. This ensures that all of the nodes in the cluster have the best knowledge of the predicted mobility states.

B. Mobility-Time Division Multiplexing Access (M-TDMA)

No slot is left; the head node will check the placeholder and future remaining half bandwidth. Similarly, a new node may not receive the slot assignment in the third slot if the cluster head is out of range or its packet had collision with other packets in the second slot. In both cases, the node has to randomly back off and retransmits its ID in the next round. In the data part, nodes transmit and receive based on a normal TDMA mechanism. Figure 5 shows M-TDMA protocol.

C. Mobile Cluster-MAC

To support mobility MC-MMA is schedule-based MAC protocol extended over Lightweight-MAC [37] and Gateway-MAC [17]. This protocol was invented to optimize the fluctuation of nodes once they travel in groups such as healthcare applications whereby a group of biomedical sensors are attached to the patient body and as he moved, sensor moved as well. Mobile-based MAC protocol can either operate statically or mobility, such as MC-MMA. Static node transmits the data in a very specific data slot. The nodes communicate with each other in static active slot (SAS) through reserving a specific transmission slot in a hop dynamically. The working principle of the static modes is described in Figure 6 (a).

Mobile sensors communicate with each other through the MCS part. Mobile sensors can be assigned to a common node as long as the size of the cluster can be small and enclose with each other. In case of multiple clusters, CSMA avoid collision between two mobile nodes. Random time will be selected by a mobile sensor in CSMA period to sense the medium before data transmission. Figure 6(b) illustrates that.

Table 2
Comparison between the previous Scheduling based protocols

Protocol	Technique	Strength	Weakness
M-MAC	Auto-regression model/Kalman Filter	Time slot is allocated dynamically by changing the frame's size and the proportion within a frame The proportion within a frame is changed more frequently than the frame size	Computational complexity Rely on AR-1 model for accuracy issue Mobility is estimated
M-TDMA	Information theoretic model	No collision No reliance on localization algorithm. Adapting to mobility without frame size changes	Many assumptions are involved Dis-connectivity may occur Latency and energy are increased
MC-MAC	Linear model	Guard time ensures de- centralized frame synchronization. In the SAS part, transmission slot is dynamically selected	Collision can't be avoided and could be happened due to hidden terminal problem. Bandwidth can be limited

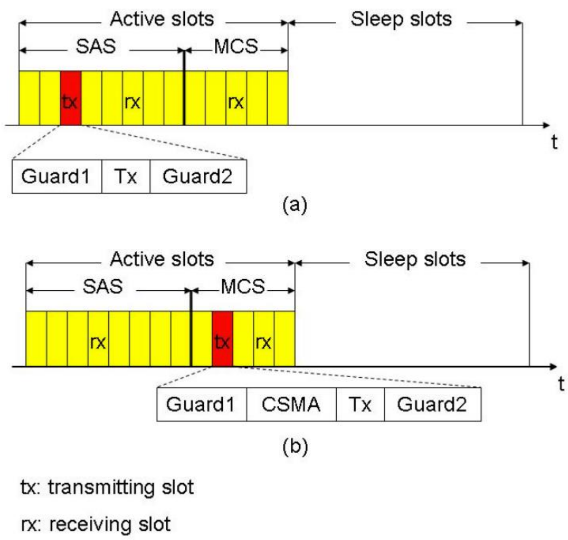

Figure 6: MCMAC architecture [36]

IV. Hybrid Contention-Based and Scheduling-Based MAC Protocols

The main aim of hybrid protocols is to exploit the advantages of both contention-based and TDMA-based MAC at the same time. The main idea behind hybrid protocol is splitting the access channel into two parts. The first part is the random access channel; the second part is the scheduled channel. The control packets will be sent through the random access channel, whereas the data will be transmitted through scheduled channel. Hybrid protocols outperform both TDMA-based MAC and contention-based in terms of energy saving, flexibility and scalability. Z-MAC [38], A-MAC [39] and IEEE 802.15.4 are examples of hybrid protocols in MAC layer.

A. Z-MAC

Z-MAC is a combination of TDMA and CSMA. Z-MAC is based on CSMA, whereas TDMA is used to refine the contention-based decision. The main concept behind Z-MAC is the "owner slot". Owner slot means that node has the assurance of ability to access its owner slot for TDMA style and CSMA style. Thus, the number of collisions will be reduced, as well as the energy consumption will be less. Neighbor discovery with slot assignment and local framing with synchronization are main elements in Z-MAC. The neighbor discovery with slot assignment is responsible for forming TDMA group and allocating the slot for the node. Local framing with synchronization determines the time frame. Except for implanting global clock synchronization at the setup phase, Z-MAC is free of synchronization and provides flexible time-frame rule.

B. A-MAC

A-MAC is a hybrid MAC protocol of CSMA and TDMA protocols. The main aim of this protocol is to have free collision scheme, no-overhearing and idle-listening transmission services and to enhance the accessibility of the wireless channel. This protocol mostly suited for long term surveillance and monitoring applications. In those applications, wireless nodes are observant for a long time and inactive in the same time up until something detected. Latency may be introduced to tolerance level. The lifetime for such a WSN is prolonged. The distinguished characteristic of A-MAC is that nodes are notified in advance before they receive the packets. A unique time slot is allocated to each node within its two hop neighbors. Nodes utilized of these pre-assigned time slot to transmit data and avoid interference. In addition, A-MAC uses its advertisement scheme to allow sender to notify its neighbors about the transmission schedule.

C. IEEE 802.15.4

IEEE 802.15.4 was designed for low-rate Wireless Personal Area Networks (WPAN). The structure of this protocol consists of two periods, TDMA-based period for ensured access, and a contention-based period for non-insured access. The nodes are able to switch off their radios and get in the sleep mode. To keep the synchronization of time frames, the coordinator is available to deal with the beaconed mode. In addition, IEEE 802.15.4 has the ability to run in ad-hoc based mode. Contention-based period in the time frame is only available for this case. Typical CSMA/CA is utilized in order to settle the contention in the contention- based period. IEEE 802.15.4 has no unique design for energy preservation scheme. Thus, this protocol uses the standard duty cycle controlling scheme for energy preservation. The hybrid protocols have two main issues. The first issue is the overhead; this issue happens due to the large size of the control packet. Whereas; the second issue is wasting energy, this issue occurs because of switching between the modes. Switching between the modes wastes energy and increases the latency as well.

V. Conclusion

A critical review on existing wireless and mobile energy efficient medium access control has been carried out with a performance comparison among the reviewed protocols, in order to guide the reader to select the proper protocol for further development. In this paper, a combative review of energy consumption on Contention-Based MAC protocols, Algorithmic based MAC protocol and Hybrid based MAC protocols stated the strengths and drawbacks with every utilized technique.

References

[1] N. A. A. Aziz and K. A. Aziz, "Managing disaster with wireless sensor networks," in *Advanced Communication Technology (ICACT), 2011 13th International Conference on*, 2011, pp. 202-207.

[2] A. Ghobakhlou, A. Perera, P. Sallis, O. Diegel, and S. Zandi, "Environmental monitoring with wireless sensor network," 2009.

[3] A. Pawlowski, J. L. Guzman, F. Rodríguez, M. Berenguel, J. Sánchez, and S. Dormido, "Simulation of greenhouse climate monitoring and control with wireless sensor network and event-based control," *Sensors,* vol. 9, pp. 232-252, 2009.

[4] T. S. Fu, A. Ghosh, E. A. Johnson, and B. Krishnamachari, "Energy-efficient deployment strategies in structural health monitoring using wireless sensor networks," *Structural Control and Health Monitoring,* vol. 20, pp. 971-986, 2013.

[5] D. Sanz, A. Barrientos, M. Garzón, C. Rossi, M. Mura, D. Puccinelli*, et al.*, "Wireless sensor networks for planetary exploration: Experimental assessment of communication and deployment," *Advances in Space Research,* vol. 52, pp. 1029-1046, 2013.

[6] D. Mao and C. Wang, "Target tracking in wireless sensor networks," *Piezoelectrics & Acoustooptics,* vol. 6, p. 040, 2011.

[7] X. Wang, M. Fu, and H. Zhang, "Target tracking in wireless sensor networks based on the combination of KF and MLE using distance measurements," *Mobile Computing, IEEE Transactions on,* vol. 11, pp. 567-576, 2012.

[8] O. Demigha, W.-K. Hidouci, and T. Ahmed, "On energy efficiency in collaborative target tracking in wireless sensor network: a review," *Communications Surveys & Tutorials, IEEE,* vol. 15, pp. 1210-1222, 2013.

[9] E. Xu, Z. Ding, and S. Dasgupta, "Target tracking and mobile sensor navigation in wireless sensor networks," *Mobile Computing, IEEE Transactions on,* vol. 12, pp. 177-186, 2013.

[10] L. Xie, Y. Shi, Y. T. Hou, and A. Lou, "Wireless power transfer and applications to sensor networks," *Wireless Communications, IEEE,* vol. 20, pp. 140-145, 2013.

[11] J. Suhonen, M. Kohvakka, V. Kaseva, T. D. Hämäläinen, and M. Hännikäinen, *Low-power wireless sensor networks: protocols, services and applications*: Springer Science & Business Media, 2012.

[12] W. Dargie, "Dynamic power management in wireless sensor networks: State-of-the-art," *Sensors Journal, IEEE,* vol. 12, pp. 1518-1528, 2012.

[13] P. Huang, L. Xiao, S. Soltani, M. W. Mutka, and N. Xi, "The evolution of MAC protocols in wireless sensor networks: A survey," *Communications Surveys & Tutorials, IEEE,* vol. 15, pp. 101-120, 2013.

[14] Y. Li and M. T. Thai, *Wireless sensor networks and applications*: Springer Science & Business Media, 2008.

[15] L. Deliang and P. Fei, "Energy-efficient MAC protocols for Wireless Sensor Networks," in *Proceedings of the IEEE Infocom, New York, USA,* 2009.

[16] S. Agarwal, V. Jain, and K. Goswami, "ENERGY EFFICIENT MAC PROTOCOLS FOR WIRELESS SENSOR NETWORK," 2013.

[17] Q. Dong and W. Dargie, "A survey on mobility and mobility-aware MAC protocols in wireless sensor networks," *Communications Surveys & Tutorials, IEEE,* vol. 15, pp. 88-100, 2013.

[18] W. Ye, J. Heidemann, and D. Estrin, "An energy-efficient MAC protocol for wireless sensor networks," in *INFOCOM 2002. Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, 2002, pp. 1567-1576.

[19] L. Mahajan and S. Kaur, "Power Saving MAC Protocols for WSNs and Optimization of S-MAC Protocol," *International Journal of Engineering Business Management,* vol. 4, 2012.

[20] H. Pham and S. Jha, "An adaptive mobility-aware MAC protocol for sensor networks (MS-MAC)," in *Mobile Ad-hoc and Sensor Systems, 2004 IEEE International Conference on*, 2004, pp. 558-560.

[21] A. Jhumka and S. Kulkarni, "On the design of mobility-tolerant TDMA-based media access control (MAC) protocol for mobile sensor networks," in *Distributed Computing and Internet Technology*, ed: Springer, 2007, pp. 42-53.

[22] T. Van Dam and K. Langendoen, "An adaptive energy-efficient MAC protocol for wireless sensor networks," in *Proceedings of the 1st international conference on Embedded networked sensor systems*, 2003, pp. 171-180.

[23] J. Kabara and M. Calle, "MAC protocols used by wireless sensor networks and a general method of performance evaluation," *International Journal of Distributed Sensor Networks,* vol. 2012, 2012.

[24] A. A. a. G. Alkhatib, Baicher S, "MAC layer overview for wireless sensor networks," in *2012 International Conference on Computer Networks and Communication Systems (CNCS) 2012*, 2012.

[25] R. Yadav, S. Varma, and N. Malaviya, "A survey of MAC protocols for wireless sensor networks," *UbiCC journal,* vol. 4, pp. 827-833, 2009.

[26] I. Demirkol, C. Ersoy, and F. Alagoz, "MAC protocols for wireless sensor networks: a survey," *Communications Magazine, IEEE,* vol. 44, pp. 115-121, 2006.

[27] M. Buettner, G. V. Yee, E. Anderson, and R. Han, "X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks," in *Proceedings of the 4th international conference on Embedded networked sensor systems*, 2006, pp. 307-320.

[28] M. R. Ahmad, E. Dutkiewicz, and X. Huang, *A survey of low duty cycle mac protocols in wireless sensor networks*: INTECH Open Access Publisher, 2011.

[29] Z. Tang and W. Dargie, "A mobility-aware medium access control protocol for wireless sensor networks," in *the fifth IEEE international workshop on Heterogeneous, Multi-Hop, Wireless and Mobile Networks*, 2010.

[30] Y. Sun, O. Gurewitz, and D. B. Johnson, "RI-MAC: a receiver-initiated asynchronous duty cycle MAC protocol for dynamic traffic loads in wireless sensor networks," in *Proceedings of the 6th ACM conference on Embedded network sensor systems*, 2008, pp. 1-14.

[31] L. Tang, Y. Sun, O. Gurewitz, and D. B. Johnson, "PW-MAC: An energy-efficient predictive-wakeup MAC protocol for wireless sensor networks," in *INFOCOM, 2011 Proceedings IEEE*, 2011, pp. 1305-1313.

[32] M. Ali, T. Suleman, and Z. A. Uzmi, "MMAC: A mobility-adaptive, collision-free mac protocol for wireless sensor networks," in *Performance, Computing, and Communications Conference, 2005. IPCCC 2005. 24th IEEE International*, 2005, pp. 401-407.

[33] Z. R. Zaidi and B. L. Mark, "Mobility tracking based on autoregressive models," *Mobile Computing, IEEE Transactions on,* vol. 10, pp. 32-43, 2011.

[34] A. Jhumka and S. Kulkarni, "On the Design of Mobility-Tolerant TDMA-Based Media Access Control (MAC) Protocol for Mobile Sensor Networks," in *Distributed Computing and Internet Technology*. vol. 4882, T. Janowski and H. Mohanty, Eds., ed: Springer Berlin Heidelberg, 2007, pp. 42-53.

[35] M. Demirbas, A. Arora, V. Mittal, and V. Kulathumani, "A Fault-Local Self-Stabilizing Clustering Service for Wireless Ad Hoc Networks," *Parallel and Distributed Systems, IEEE Transactions on,* vol. 17, pp. 912-922, 2006.

[36] Q. Dong and W. Dargie, "A survey on mobility and mobility-aware MAC protocols in wireless sensor networks," *Communications Surveys & Tutorials, IEEE,* vol. 15, pp. 88-100, 2013.

[37] M. Nabi, M. Blagojevic, M. Geilen, T. Basten, and T. Hendriks, "MCMAC: An optimized medium access control protocol for mobile clusters in wireless sensor networks," in *Sensor Mesh and Ad Hoc Communications and Networks (SECON), 2010 7th Annual IEEE Communications Society Conference on*, 2010, pp. 1-9.

[38] I. Rhee, A. Warrier, M. Aia, J. Min, and M. L. Sichitiu, "Z-MAC: a hybrid MAC for wireless sensor networks," *IEEE/ACM Transactions on Networking (TON),* vol. 16, pp. 511-524, 2008.

[39] Y. Liu and L. M. Ni, "A new MAC protocol design for long-term applications in wireless sensor networks," in *Parallel and Distributed Systems, 2007 International Conference on*, 2007, pp. 1-8.