MAC Protocol Design Requirements for Mobility-aware Wireless Sensor Networks

Adrian Kacsó and Wajahat Abbas Kazmi

Department of Electrical Engineering and Computer Science
University of Siegen, Germany
Email: [adrian.kacso, syed.kazmi]@uni-siegen.de

***Abstract*—The usage of mobile nodes is a requirement in some wireless sensor networks (WSNs) applications (wildlife or patient monitoring). They require that data packets are sent reliably, mainly as bursty traffic with low energy consumption and low latency to a base station for monitoring. Mobility of nodes introduces several communication challenges, such as frequent topological changes, intermittent connectivity, and increase in collision rate. In order to fulfill the application requirements (e.g., energy efficiency, reliable transmissions, lower end-to-end latency) low duty-cycle, mobility-aware medium access (MAC) protocols have been proposed. The paper describes the main characteristics of recent mobility-aware MAC protocols, including our protocol, highlighting their assumptions and working mechanism, their advantages and limitations. It presents concrete application constraints and protocol features for designing MAC protocols for mobility-aware WSNs. Moreover, challenges in the evaluation of the proposed MACs are discussed and prospective future directions are identified.**

Keywords–wireless sensor network; mobility-aware Mac protocols; reliable, burst traffic; mobile WSNs; simulation

I. Introduction

While the initial research on wireless sensor nodes (WSN) medium access protocols (MACs) assumed static nodes only, it becomes obvious that mobility support is necessary for many application scenarios, e.g., wildlife and patient monitoring. Thus, we analyze first the existing mobility-aware MAC protocols with their achievements and drawbacks. In this paper, we consider mobile nodes aiming to report their data with minimal delay by establishing a communication link with a static or fixed node towards the sink. We refer to WSNs containing mobile nodes as Mobile Wireless Sensor Networks (MWSNs) in this paper. The design concerns for MAC in MWSNs significantly differ from that of cellular systems and Mobile Ad-hoc Networks (MANETs) in spite of the common aspect of mobility in these networks. In cellular systems, mobile nodes are directly connected to the base station having a single hop, versus multiple hops in MWSNs. Also, energy conservation is not an important design constraint in cellular systems because the base station and mobile nodes are not energy constrained. In addition, contrary to cellular networks, the handover process in MWSNs is more complex because relay nodes in MWSNs are not resourceful like base stations in cellular networks. MANETs are also not having energy-related issues and the main focus of MAC design is on quality of service provisioning.

Research in the area of WSNs focused primarily on improving energy efficiency and prolonging network lifetime whereas factors as mobility, latency, throughput, reliability, scalability were treated as secondary concerns so far. Numerous MAC layer designs for static WSNs have been proposed by researchers. The protocols and algorithms presented in these proposals were surveyed to acquaint researchers with the state-of-the-art in the field. Apart from categorizing the protocols into different classes (synchronous, asynchronous, frame-slotted, multichannel), [1] presents the evolutionary development of MAC protocols in addressing problems that fall in the domain of these classes of protocols. In [2], Bachir et al. identify collisions, overhearing, protocol overhead and idle listening as the main sources of energy consumption on the basis of problems they intend to address. Problems that occur due to mobility in MWSNs, particularly energy and reliable delivery related issues, need to be addressed and investigated.

Synchronous MAC protocols are based on common active/sleep schedules, where the clock is used to wake up the nodes for a specific period at given synchronization points in time. Nodes having the same schedule build a cluster. Such protocols require clock synchronization among all the nodes belonging to the same cluster. Synchronous protocols can be employed in MWSNs applications, where a cluster of nodes is attached to a moving target (person, animal, device), yielding a fix network topology, where a tight synchronization between nodes can be achieved. Even here, it remains challenging to detect mobile nodes and try to ensure communication with as few as possible disconnections when moving among different clusters, while also considering energy constraints of border nodes (in charge of seamless handing over for mobile nodes).

Asynchronous MAC protocols are based on preambles to announce a transmission. They require neither time synchronization nor schedule dissemination. Each node operates distributively and can choose its active schedule independently from other nodes. Therefore, such protocols are more scalable and robust to topology changes in the network. Asynchronous protocols can be more efficient than synchronous protocols in MWSN applications, such as wildlife monitoring, where a reliable communication between energy constrained mobile and static nodes is infrequent and energy efficiency is a primary concern. Their limitations are reduced channel availability and increased competition among the nodes. Collisions can be frequent, especially in dense networks with frequent transmissions, which would imply retransmissions and increase thus the energy consumption. Due to the mobility in dense zones, mobile nodes experience high medium access delays. Therefore, the major challenges to be considered while designing asynchronous MAC protocols for MWSNs are duty cycling of

 ISBN: 978-1-61208-580-7

mobile node, medium access contention and communication efficiency as well as handover and reconnection of mobile nodes.

In [3], Ding et al. provide a survey of MAC protocols for MWSNs proposed until 2011 and present the available mobility models and mobility estimation techniques. It discusses the characteristics, advantages and disadvantages of the following mobility-aware MAC protocols: MS-MAC [4], MMAC [5], M-TDMA [6], MA-MAC [7], MobiSense [8], and MCMAC [9]. In [10], authors presented a survey of MAC protocols for MWSNs proposed till 2013. It gives a general classification of WSN mobility based on type of mobile element, type of movement, protocol level considerations and type of mobility handling entity. It summarizes WSN mobility solutions proposed at MAC and network layer and few MAC layer protocols: MS-MAC [4], MOBMAC [11], AM-MAC [12], MD-SMAC [13], MMAC [5], CFMA-MAC[14], MoX-MAC [15], MAMAC [16] and MMH-MAC [17]. In [18], the authors highlight advantages and drawbacks of protocols proposed until 2009 besides their own protocol Machiavel [19].

The contributions of this paper are twofold: we present 1) the main contributions of some relevant MAC protocols for MWSNs (since 2013) and discuss their working mechanism, advantages and limitations to identify research achievements; 2) our Mob-MAC protocol design and identify prospective future direction on this topic. This paper is structured as follows. Section II presents a discussion of the relevant MAC protocols including our Mob-MAC protocol for MWSNs. Section III provides conclusions and future directions.

II. Design issues in MAC protocols for MWSNs

In this section, we investigate a group of MAC protocols for MWSNs according to their application assumptions and the existing sensor network deployment. We group them into preamble sampling (asynchronous) and cluster-based (synchronous) protocols.

TABLE I. Summary of relevant MAC protocols for MWSNs.

Protocol	A/S	Derived from	Major problem addressed
M-ContikiMac [20]	A	ContikiMAC [21]	Handling bursty traffic
ME-ContikiMAC [22]	A	ContikiMAC [21]	Handling bursty traffic
X-Machiavel [18]	A	X-MAC [23]	Delays in burst transmission and reconnection
MoX-MAC [15]	A	–	Overhead minimization
MT-MAC [24]	S	T-MAC [25]	High packet drop rate during handover
MS-SMAC [26]	S	S-MAC [27]	Mobile node disconnection due to speed variation
MobIQ [22]	A	ContikiMAC [21]	Neighbor discovery, Channel contention, Hidden terminal problem
MobiDisc [28]	A	ContikiMAC [21]	Delays in burst transmission, handover and reconnection

We consider large sensor networks, where a large number of static and mobile nodes coexist. It is assumed that static nodes build a routing backbone (convergecast communication infrastructure), e.g., a tree rooted at a sink, in which each static node has a parent. A mobile node knows (or it is able to detect) that it is mobile and does not forward data packets. A mobile node establishes communication links with (randomly) static nodes in order to inject their data in the backbone. Static nodes forward the data hop by hop to the sink. Mobile nodes are considered more energy constrained that static nodes. Due to the mobility, disconnections between mobile nodes and the static infrastructure are frequent and common use cases. Networks are dense enough (a mobile node finds at least a static node in the vicinity). The application requirements are high packet delivery ratio at sink, low end-to-end latency, energy efficient transmissions of relevant data in a burst. Our objective is to address mobility efficiently under burst traffic in high density WSNs by achieving low end-to-end and handover delays, low energy consumption and prolonged lifetime. Table I presents some relevant MAC protocols for MWSNs showing their working scheme (column *A/S*: A=Asynchronous, S=Synchronous), the protocol from which they are derived and the major problems addressed by them.

A. Synchronous MAC Protocols for MWSNs

Synchronous MAC protocols for MWSNs use the cluster topology to handle mobility. Schedules are propagated by broadcasting SYNC packets at the beginning of the listen phase every predefined number of cycles. When a mobile node moves out of its original cluster range, it should receive a SYNC packet from the border node, deployed between the two clusters, in order to learn as soon as possible the new schedule. The next protocols use different methods to handoff the mobile node to another cluster.

1) MT-MAC [24] : is an extension of T-MAC [25], a synchronous protocol that adopts an adaptive duty cycle according to the variation in traffic load. The mechanism of MT-MAC is divided into two phases, namely the scheduling phase and mobility handling phase.

In the scheduling phase, nodes are classified adaptively into stationary node, border node, cluster head and mobile node, where each node belongs to at least one virtual cluster.

In the mobility phase, upon receiving a SYNC packet, a static node observes the Received Signal Strength Indicator (RSSI) and Link Quality Indicator (LQI) values. In case a change in RSSI and LQI values is above a certain threshold, it is considered that the node is mobile and a timer is triggered. If a node marked as mobile stays in the same cluster more than a particular time, it is considered that the node is static. Based on the above mechanism, when a border node detects that a mobile node is approaching, it informs the node about the schedule of the next cluster. Thus, the mobile node can perform handover in an organized manner.

Limitations of the protocol are: a) Mobility estimation using RSSI and LQI is not reliable. b) MT-MAC is only suited when the mobile node is not energy constrained. If the mobile node is energy constrained, keeping the schedule of both clusters is not optimal. c) If there are more mobile nodes and the border nodes are energy constrained, the interactions with mobile nodes will consume much energy of the border nodes. The scheduling phase must be reinitiated periodically to select other border nodes.

2) MS-SMAC [26] : proposes a mechanism that reduces the probability of disconnection of mobile node with neighboring nodes when the speed of mobile node changes during movement. It is designed based on the fact that existing mobility-aware MAC protocols for WSNs do not show adaptive behavior to the change of mobile node speed.

Upon entering a new cluster, a mobile node broadcasts its speed and direction. The static nodes in the cluster acknowledge the packet sent by the mobile node, also providing information about their next sleep time and next announcement interval (when mobile node should send update about its current speed). An acknowledgment sent by border nodes contains information about sleep times of the current and the neighboring cluster.

Mobility estimation, as well as localization of mobile nodes is performed by a mechanism that makes use of the three largest RSSI values to reference neighboring nodes. The protocol also introduces a mechanism to provide up-to-date information to mobile and static nodes about active cycles of other nodes to ensure better connectivity between nodes.

Limitations of the protocol are: a) Mechanism for mobility estimation and handover decision introduce significant overhead. b) Mobility estimation and localization using RSSI is not reliable. c) The implicit assumption regarding the numbers of nodes in the cluster is not clear. The mechanism for localization needs three RSSI values, thus assuming the presence of at least three nodes in the cluster. If the number of nodes in the network, particularly mobile nodes, is high the protocol performance will be degraded due to complex computations involved in mobility estimation and handover.

B. Asynchronous MAC Protocols for MWSNs

A variety of applications involving mobility, such as patient and wildlife monitoring, require data to be transmitted in bursts. This occurs in scenarios where mobile nodes have occasional contact with different static nodes in the network and need to transmit urgently relevant sensed data. Relevant asynchronous MAC protocols send strobed preambles to notify potential receivers and use additional mechanisms to achieve better performance.

1) M-ContikiMAC [20]: is an extension of the ContikiMAC protocol [21], which is the default duty cycling mechanism in ContikiOS [29]. It is a preamble sampling protocol designed for static networks employing unicast and broadcast transmissions. It uses a special mechanism to handle bursty traffic in the network. The node intending to transmit a burst of packets informs the receiver about more packets in a row by setting a burst flag.The receiver on observing this flagged data keeps its radio *on* to receive more packets until the transmission is over. For the last packet in the burst, the flag will not be set, and, this way, efficient burst handling is achieved.

In M-ContikiMAC, a mobile node is not aware of the next hop in the rooting tree. Therefore, it cannot use unicast and must broadcast at least in the first step. It has to find out the address of a static neighbor node in the tree to communicate with it. M-ContikiMAC uses an anycast transmission, which allows the first node, the one that received the anycast packet and acknowledged it, to be the real recipient for the next packets in the burst.

If a mobile node is intending to send packets in burst, it sets besides the burst flag a byte field (*ReqHop*) to discover a static parent node. A static receiver, upon receiving an anycast packet, checks the value of the field. If the value is zero, it receives the packet and sends an acknowledgment informing the transmitter node about its address for unicast transmission. The receiver keeps its radio on to receive the burst from the sender. When the mobile sender receives the acknowledgment, it sets the byte field to the address of the receiver and unicasts the remaining packets (starting with the 2nd data packet) to it. In case of disconnection with the receiving node, the mobile sender sets the field to 0 again and repeats the same procedure to find a new potential receiver node as relay to sink.

Limitations of the protocol are: a) Useless forwarding of the 1st data packet on the route to sink. b) The collision of the ACKs. c) Mobile node disconnection from temporary parent. All these are correlated. Let us assume that two receiver nodes receive simultaneously a packet (either the 1st or one during reconnection). They will reply with an acknowledgment at (near) the same time, which collide at the sender. According to M-ContikiMAC, these nodes will keep their radio on and forward the first received data packet on several routes to the sink. The sink detects packet duplication and the useless traffic produces congestion, high latency and high energy consumption.

2) ME-ContikiMAC [22]: overcomes the limitations in M-ContikiMAC. In ME-ContikiMAC, the mobile node sends a control packet using anycast instead of the first data packet. The control packet is not forwarded by receiving nodes. Even if acknowledgements from two or more receivers collide, the control packet will not be forwarded to the sink. The mobile node will retransmit the control packet and will not initiate burst transmission until it receives an acknowledgment from any receiving node, which reduces packet duplication in the network. The same mechanism is used for reconnections.

Limitations of the protocol are: a) Receiver nodes send the acknowledgment upon receiving the control packet and switch the radio on waiting for the next packets in the burst. If the acknowledgments collide, the receivers are not aware about it and loose energy waiting for the burst. b) During bursts, a new mobile or static node can generate the hidden station problem. Moreover, an aggressive mobile mode (i.e., sending control packets without waiting the next preamble cycle) may affect the communication of the static nodes. c) For dense networks, it is necessary to avoid the collision of the ACKs; (the control packet is resent until the ACK is received). d) If the mobile node doesn't receive its expected ACK, the burst is postponed for the next preamble cycle, which increases the latency.

3) X-Machiavel [18]: takes benefit of the strobed preamble mechanism used by X-MAC to include mobile nodes in the communication. Data packets initiated by a mobile node have higher priority compared to those of static/fixed nodes. A mobile node, before a transmission, overhears the medium and 'steals' the medium from a static node already involved in a not guarded incipient communication (either with a special preamble or a flag). The idea is based on the fact that mobile nodes are energy constrained and without sending a preamble, they insert their data after overhearing a preamble of the intended static receiver. The communication between static nodes can be postponed, which may induce message buffering, retransmissions and latency in the static routing infrastructure. The protocol uses a special header that is included in the preamble, data and ACK packets. The header contains a *type* that allows to use various preambles or acknowledgements and a *flag* byte, where the M-bit informs each relay receiver that the data is from a mobile node on the way to sink, and the medium cannot be stolen by a mobile. A special preamble type prevents potential forwarders to claim the data.

Limitations of the protocol are: a) Complex implementation, special header added to each frame type. b) If the final destination of the data packet acknowledges a preamble later than a static forwarder in the same vecinity, the forwarding is not optimal and the latency increases. c) Unfairness, data initiated from a mobile node have higher priority than from a static one. d) Two or more ACKs from potential receivers may collide, which triggers a retransmission.

4) MoX-MAC [15]: allows a mobile sender to overhear an ongoing transmission between two static nodes, in order to send his own data to the static sender at the end of the ongoing transmission. Limitations of the protocol: a) Mobile nodes must be in the range of both communicating static sender and receiver. b) Since the mobile node must use the basic X-MAC scheme if no ongoing transmission is detected, the efficiency of the approach is highly dependent on the frequency of transmissions between the static nodes.

5) MobIQ [30]: proposes a mechanism to enable efficient neighbor discovery for mobile nodes, reduction of channel contention and overcoming hidden terminal problems.

Mobile nodes, due to their movement (or link disconnections), often have to change their static next-hop in order to send all the data packets of a burst. An efficient handover mechanism allows mobile nodes to maintain an uninterrupted communication with the static routing backbone. This can be achieved with a fast neighbour discovery and regular updates from the neighborhood. For discovering and selecting an appropriate neighbor, the mobile node continuously anycasts control packets for the whole preamble duration to assure that all neighbors receive them. All receivers acknowledge it by sending their ID and routing metrics (e.g., hops to sink, remaining battery) to the mobile node. Between all its potential receivers, the mobile node selects the best next forwarder node on the route to sink (the network layer provides the metrics to the link layer) and starts burst transmission in the next sampling period.

To avoid channel contention during transmission of burst packets, the mobile node informs the nodes about the queue length in every data packet. Using this queue length information, receiver nodes can adjust their sleep schedule. To avoid the hidden terminal problem, where more than one mobile node send data to the same receiver, the receiver node disseminates the queue length information of the current sender in ACK packets, by overhearing which other intending sender(s) can adjust their wait period accordingly.

Limitations of the protocol are: a) Neighbors of mobile node will come to know which node was selected by the mobile node once it starts the burst transmission; therefore, all neighbors will wake up in the next sampling period, which will result in energy consumption for nodes which were not selected. b) Since two or more ACKs from potential receivers may collide, the mobile node may select not the best forwarder.

6) MobiDisc [28]: an extension of MobIQ, introduces the First Ack Next-hop (FAN) mode, which enables reduction of delays in transmission of bursts by allowing mobile sender nodes to select a better (according to some routing metrics) forwarder node on the route to sink. Using the FAN mode, if another static forwarder samples the medium during the ongoing burst transmission of the mobile node with the first forwarder, then it will inform the mobile node about its metric using a notification packet. Later, the mobile node may decide to select the second forwarder (according to it metrics) and perform a handover.

During burst transmission, mobile node may get disconnected from its current static receiver. The Fast Recovery Mechanism (FRM) aims at reducing the handover and reconnection delays by granting priority to traffic of mobile nodes over that of static nodes. Thus, upon discovery of disconnection, the mobile node immediately starts sending control packets to search for a new potential receiver within the same preamble cycle.

Limitations of the protocol are: a) In FAN mode the energy consumption of both mobile and static nodes increases (due to extended listening time to receive the notification and more Clear Channel Assessment (CCA) slots). b) The protocol does not consider the possibility of medium access conflicts between more mobile nodes getting disconnected in the same vicinity, while discussing FRM.

7) Mob-MAC: is our proposal. We opt for a preamble based MAC approach, since, in our use cases, the mobile node is energy constrained. When a mobile node has data to send, it broadcasts a preamble as a strobe control frame, containing a *ReqHop*, a flag, and a *type* field. The *ReqHop* field is set to a default anycast address (denotes either all or a given receiver), the flag tells the receiver that the packet is from a mobile node, it is urgent, and the type grants frames different priorities. The control frame serves to inform the vicinity that the mobile node is searching a receiver as forwarder of its data. To assure that all neighbors of the mobile sender receives the control frame, it is transmitted the whole preamble period. The mobile nodes have to switch often their next hop node, due to its mobility across the static node infrastructure, link quality fluctuations and disconnections. An efficient handover mechanism allows mobile nodes to establish a communication link with the static infrastructure by switching reactively between different static forwarder nodes. The handover is implemented only in the mobile nodes, as they are known in advance. Both static and mobile nodes are designed using cross-layering, since routing or application layer information (e.g., routing metrics of a path to sink, or latency requirements) is made accessible to the MAC layer. Thus, when a static receiver as potential forwarder acknowledges a control frame, it informs the mobile node about its address and its metrics (the cost on the route to sink through this forwarder). After that, the static node switches off its radio until the next preamble sampling period. The mobile node, by comparing the metrics, selects the best forwarder and starts the burst transmission in the next preamble period. Each potential forwarder wakes up during that period and by receiving one of the packet inside the burst, concludes that was not selected and switch off its radio. During the burst transmission, the mobile node may be disconnected from its current forwarder or the neighborhood can provide info to the mobile node, suggesting it to change the forwarder if there is a most appropriate one. In case of disconnection, the mobile node starts by sending control frames. In case one of the neighbors overhears the i-th data transmission inside an ongoing burst, it informs (similar principle to FAN) the mobile node about its better metrics. In order to activate this mode of operation, the mobile node must wait a given time after the ACK reception (similar to the TA in T-MAC), in order to get the new information and later to switch the forwarder when transmitting the $(i+1)$-th data packet.

The communication initiated by a mobile node is considered having higher priority that the transmission between static nodes and therefore, a mobile node can steal the medium from an ongoing communication between two static nodes, except the case when the data was originated from a mobile node.

First results using the new Mob-MAC indicate performance improvements in our scenarios concerning increased packet delivery rate at sink and lower end-to-end delay with a very small increase in energy consumption.

We have evaluated our protocol by comparing it with implementations of mobile variants of T-MAC and X-MAC in the MiXiM/OMNeT++ Framework Simulator using a random waypoint mobility model. The mobility models specify the mobility pattern used by the mobile nodes. In random waypoint mobility model, the mobile node pauses for a fixed period and then moves from an initial to a final position by randomly choosing the speed and direction within a given time or distance. When the given time elapses or the distance has been reached, the node pauses again, adopts a new direction and speed and moves to another location. Furthermore, the model where the mobile node moves to the next destination without pausing is referred to as Random Walk model.

TABLE II. COMPARISON AND EVALUATION OF THE MAC PROTOCOLS.

Protocol	Performance compared with	Mobility model	Evaluation using
ME-ContikiMAC [22]	MoX-MAC[15], MOBINET[31], M-ContikiMAC [20]	Random waypoint	COOJA simulator
MX-MAC [32]	—	—	TinyOS (IMote2 platform)
MT-MAC [24]	MS-MAC[4], T-MAC [25]	Random walk, Random waypoint	Castalia Simulator
MS-SMAC [26]	S-MAC[27], MS-MAC [4], MMAC[5]	—	TOSSIM simulator
MobIQ [30]	MoX-MAC [15], MOBINET[31], ME-ContikiMAC[22]	Random waypoint	ContikiOS (Tmote-Sky platform), COOJA simulator
MobiDisc [28]	MoX-MAC[15], ME-ContikiMAC [22]	Random waypoint	ContikiOS (Tmote-Sky platform), COOJA simulator
Mob-MAC	MT-MAC/RB [33],	Random waypoint	MiXiM / OMNet++ Simulator

Table II presents the simulators/testbeds used for evaluation of all discussed protocols and the mobility models used. The protocols contained in the first column of the table extend and/or improve the corresponding protocols cointained in the second column.

III. CONCLUSIONS AND FUTURE DIRECTIONS

Most of the proposed MAC protocols for MWSNs extend the existing protocols designed for static nodes and therefore inherit their drawbacks. The concerns regarding the design of mobility-aware MAC protocols presented in this paper need to be addressed while designing new mobility-aware MAC protocols for WSNs. Based on our findings, we present few prospective future directions for MAC protocol design in MWSNs.

• *Reduction of the overhead on energy-constrained mobile nodes:* Most MAC protocols designed for MWSNs assume that mobile nodes are not energy constrained, which is not the case in some practical scenarios such as in wildlife or person monitoring. When designing scenarios with energy constrained mobile nodes, the aspect of overhead on mobile nodes needs to be taken into consideration.

• *Enabling reliable bursty transmission in MWSNs:* Although some solutions have been proposed for burst transmission in MWSNs, the focus is merely on enabling burst transmission rather than providing reliability. In emergency situations, such as fire monitoring or healthcare reliable burst transmission is required because providing insufficient information may cost human lives. Thusm solutions providing reliable burst transmission in MWSNs need to be designed.

• *Providing fair media access is a challenging task in dense MWSNs:* The situation becomes much more complex when mobile nodes are present in a WSN which has energy constrained static nodes having critical data. Many previously proposed MAC solutions for WSNs with mobile nodes assume that media access will be granted to mobile nodes as soon as they enter the network. Therefore, it is a design issue that depends on the application if some communication should be prioritized. If vital data need to be reported immediately there must be a mechanism that will allow to differentiate between vital and not urgent data packets.

• *Improvement of overall communication efficiency in complex scenarios:* When a mobile node moves with high speed and it has a large number of packets to send, it may not be possible to send all the packets because of the short time span available for handshaking and burst transmission. Taking energy efficiency, reliability and delay constraints into consideration, efficient schemes (e.g., handovers) to improve overall communication efficiency need to be devised.

• *Using receiver-initiated preamble sampling:* In scenarios where energy constrained mobile nodes are used, receiver-initiated preamble sampling will reduce energy consumption by reducing the communication overhead on mobile sensor nodes.

• *Develop novel scheduling schemes to reduce latency in packet forwarding to the sink:* Mobile nodes moving across dense networks of static sensor nodes suffer from long medium access delays and transient disconnection. The mobile node should be able to access the medium regardless of the level of contention on the medium in order to report its collected data in burst and with minimal delay. The transmissions of the mobile node need to be integrated in the low duty-cycle communication schedule of static nodes. In case of disconnection, a neighbor discovery mechanism is needed to allow mobile nodes to keep continuous connectivity with the static infrastructure. These aspects need to be resolved at the MAC layer (according to information provided by network or application layers).

A real energy benefit is achieved when using strobe preamble sampling MAC protocols with low duty cycles. Considering the scarce energy, communication and processing resources of the mobile nodes, a joint optimization of the MAC, network and application layers by employing a cross-layer design is a promising alternative to maximize the network performance, while reducing the global energy consumption.
As future work, we continue with extensive simulations and analyze more thoroughly the performance of Mob-MAC protocol to find further possible optimizations and to validate our design.

REFERENCES

[1] P. Huang, L. Xiao, S. Soltani, M. W. Mutka, and N. Xi, "The evolution of MAC protocols in wireless sensor networks: A survey," IEEE communications surveys & tutorials, vol. 15, no. 1, 2013, pp. 101–120.

[2] A. Bachir, M. Dohler, T. Watteyne, and K. K. Leung, "MAC essentials for wireless sensor networks," IEEE Communications Surveys & Tutorials, vol. 12, no. 2, 2010, pp. 222–248.

[3] Q. Dong et al., "A survey on mobility and mobility-aware MAC protocols in wireless sensor networks," IEEE Communications Surveys and Tutorials, vol. 15, no. 1, 2013, pp. 88–100.

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

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

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

[7] T. Zhiyong and W. Dargie, "A mobility-aware medium access control protocol for wireless sensor networks," in GLOBECOM Workshops (GC Wkshps). IEEE, 2010, pp. 109–114.

[8] A. Gonga, O. Landsiedel, and M. Johansson, "MobiSense: Power-efficient micro-mobility in wireless sensor networks," in International Conference on Distributed Computing in Sensor Systems and Workshops (DCOSS). IEEE, 2011, pp. 1–8.

[9] M. Nabi, M. Geilen, T. Basten, and M. Blagojevic, "Efficient cluster mobility support for tdma-based mac protocols in wireless sensor networks," ACM Transactions on Sensor Networks (TOSN), vol. 10, no. 4, 2014, p. 65.

[10] R. Silva, J. S. Silva, and F. Boavida, "Mobility in wireless sensor networks–survey and proposal," Computer Communications, vol. 52, 2014, pp. 1–20.

[11] P. Raviraj, H. Sharif, M. Hempel, and S. Ci, "MOBMAC-an energy efficient and low latency MAC for mobile wireless sensor networks," in Proceedings Systems Communications. IEEE, 2005, pp. 370–375.

[12] S.-C. Choi, J.-W. Lee, and Y. Kim, "An adaptive mobility-supporting MAC protocol for mobile sensor networks," in Vehicular Technology Conference,VTC Spring. IEEE, 2008, pp. 168–172.

[13] S. Hameed, E. Shaaban, H. Faheem, and M. Ghoniemy, "Mobility-aware MAC protocol for delay-sensitive wireless sensor networks," in International Conference on Ultra Modern Telecommunications and Workshops (ICUMT). IEEE, 2009, pp. 1–8.

[14] B. M. Khan and F. H. Ali, "Collision free mobility adaptive (cfma) mac for wireless sensor networks," Telecomm. Systems, 2013, pp. 1–16.

[15] P. D. Ba, I. Niang, and B. Gueye, "An optimized and power savings protocol for mobility energy-aware in wireless sensor networks," Telecommunication Systems, vol. 55, no. 2, 2014, pp. 271–280.

[16] B. Liu, K. Yu, L. Zhang, and H. Zhang, "MAC performance and improvement in mobile wireless sensor networks," in Eighth ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing (SNPD), vol. 3. IEEE, 2007, pp. 109–114.

[17] L. Bernardo et al., "A mac protocol for mobile wireless sensor networks with bursty traffic," in Wireless Communications and Networking Conference (WCNC). IEEE, 2010, pp. 1–6.

[18] R. Kuntz, J. Montavont, and T. Noël, "Improving the medium access in highly mobile wireless sensor networks," Telecommunication Systems, 2013, pp. 1–22.

[19] R. Kuntz and T. Noël, "Machiavel: Accessing the medium in mobile and dense WSN," in 20th International Symposium on Personal, Indoor and Mobile Radio Communications. IEEE, 2009, pp. 1088–1092.

[20] G. Papadopoulos et al., "Enhancing ContikiMAC for bursty traffic in mobile sensor networks," in SENSORS. IEEE, 2014, pp. 257–260.

[21] A. Dunkels, "The contikimac radio duty cycling protocol," Swedish Institute of Computer Science, 2011.

[22] G. Z. Papadopoulos et al., "Wireless medium access control under mobility and bursty traffic assumptions in WSNs," Mobile Networks and Applications, vol. 20, no. 5, 2015, pp. 649–660.

[23] 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, ser. SenSys '06. New York, NY, USA: ACM, 2006, pp. 307–320.

[24] M. Zareei, A. M. Islam, A. Zeb, S. Baharun, and S. Komaki, "Mobility-aware timeout medium access control protocol for wireless sensor networks," AEU-International Journal of Electronics and Communications, vol. 68, no. 10, 2014, pp. 1000–1006.

[25] 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. ACM, 2003, pp. 171–180.

[26] F. Peng, "A novel adaptive mobility-aware MAC protocol in wireless sensor networks," Wireless Personal Communications, vol. 81, no. 2, 2015, pp. 489–501.

[27] W. Ye, J. Heidemann, and D. Estrin, "An energy-efficient MAC protocol for wireless sensor networks," in Proceedings Twenty-first annual joint conference of the computer and communications societies INFOCOM, vol. 3. IEEE, 2002, pp. 1567–1576.

[28] G. Z. Papadopoulos, V. Kotsiou, A. Gallais, P. Chatzimisios, and T. Noel, "Low-power neighbor discovery for mobility-aware wireless sensor networks," Ad Hoc Networks, vol. 48, 2016, pp. 66–79.

[29] A. Dunkels, B. Gronvall, and T. Voigt, "Contiki-a lightweight and flexible operating system for tiny networked sensors," in 29th Annual International Conference on Local Computer Networks. IEEE, 2004, pp. 455–462.

[30] G. Z. Papadopoulos et al., "A Mobility-Supporting MAC Scheme for Bursty Traffic in IoT and WSNs," in Global Communications Conference (GLOBECOM). IEEE, 2016, pp. 1–6.

[31] D. Roth, J. Montavont, and T. Noel, "MOBINET: Mobility management across different wireless sensor networks," in Wireless Communications and Networking Conference (WCNC). IEEE, 2011, pp. 351–356.

[32] W. Dargie and J. Wen, "A seamless handover for wsn using lms filter," in 39th Conference on Local Computer Networks (LCN). IEEE, 2014, pp. 442–445.

[33] A. Kacsó and U. Schipper, "Receiver-based routing service for t-mac protocol," in Proc. 4th Int. Conf. on Sensor Technologies and Applications (SENSORCOMM'10). Venice, Italy, July 18-25 2010, pp. 489–494.