World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:9, No:3, 2015

Performance Evaluation of XMAC and BMAC Routing Protocol under Static and Mobility Scenarios in Wireless Sensor Network

M. V. Ramana Rao, T. Adilakshmi

Abstract**—**Based on application requirements, nodes are static or mobile in Wireless Sensor Networks (WSNs). Mobility poses challenges in protocol design, especially at the link layer requiring mobility adaptation algorithms to localize mobile nodes and predict link quality to be established with them. This study implements XMAC and Berkeley Media Access Control (BMAC) routing protocols to evaluate performance under WSN's static and mobility conditions. This paper gives a comparative study of mobility-aware MAC protocols. Routing protocol performance, based on Average End to End Delay, Average Packet Delivery Ratio, Average Number of hops, and Jitter is evaluated.

Keywords**—**Wireless Sensor Network (WSN), Medium Access Control (MAC), Berkeley Media Access Control (BMAC), mobility.

I. INTRODUCTION

WIRELESS sensor networking, an emerging technology has a range of applications including smart spaces, environment monitoring, medical systems, and robotic exploration. These networks have many small nodes which sense various physical phenomena, partially process raw data locally, and ensure results over wireless multi-hop links [1]. Such networks have many distributed nodes which organize themselves into a multi-hop wireless network. Every node has one or more sensors, embedded processors and low-power radios, which are usually battery operated. These nodes perform a common task [2]. WSN nodes are not in isolation but are embedded in the environment, causing unpredictable network links [3]. When surrounding environment changes, nodes adjust operation to ensure connectivity.

WSN applications monitor disaster areas, patients, assisting the disabled and aiding the army. As a sensor network has many sensor nodes with batteries, sensor nodes should have low power consumption, low hardware cost, rapid deployment, small size, and must be self-organized. WSN protocols need low-power and flexible hardware platforms. WSN routing protocols increase energy efficiency when transmitting data to base stations. Based on network structure, routing protocols are flat, hierarchical, and location-based [4].

As WSN trade-offs differ from those of wireless networks, and as hardware is limited, specialized network protocols have to be designed. Network protocols are classified into layers one of which is data link layer (OSI layer 2) which provides communication at link level. A link has two nodes directly communicating via radio in wireless communication. The data link layer's partial responsibility is determining which node accesses the medium and when. This is called Medium Access Control (MAC).

This is important in a shared medium as multiple nodes transmitting simultaneously will interfere with the other's communication. MAC protocol has complex negotiations and provisions for lost messages. MAC protocol in a wireless environment, determines state of the radio on a node sending, receiving, or sleeping. As the radio, uses much energy, when listening or transmitting, the MAC is a good place to save energy [5].

Most WSN MAC protocols can deal with a slow network's topology change. For example, nodes update their knowledge about their neighbors by exchanging synchronization packets in SMAC [6] and TMAC [7]. Similarly, Preamble-based protocols like BMAC, XMAC [8] and Wise MAC [9] avoid periodic synchronization (expensive) by enabling transmitting nodes to send a preambles burst. The preamble's duration is longer than the node's sleeping duration. Thus, a receiver responds to a preamble when it wakes up. In receiver-initiated MAC protocols like RI-MAC [10], every time a receiver wakes up from sleep state it broadcasts a beacon to all neighbors informing them that it is ready to receive packets. But, all protocols help nodes perceive change in surroundings at the start of an active period. So packet transmission is delayed when a topology change happens. This delay can be high in multi-hop networks. As weak mobility is infrequent, delay introduced can be tolerable.

A new approach to low power listening called XMAC uses a short preamble to reduce energy consumption and latency. The first idea is to embed the target's address information in the preamble so that non-target receivers go back to sleep. The second is using a strobed preamble to allow target receiver to interrupt long preambles when it wakes up and determines it is the target receiver. The short strobed preamble reduces time, and the energy wasted waiting for full preamble to be completed.

BMAC is a contention-based protocol, through Low Power Listening (LPL) ensuring power management. A node maintains a listening duty cycle divided by a specific time period called check interval. Node checks activity at each check interval when it wakes up. When activity is detected, node stays awake to receive incoming packet. But, if the

M V Ramana Rao is with University College of Engineering, Hyderabad, Andhra Pradesh, India (e-mail: ramanarao.mv.cse@gmail.com).

T. Adilakshmi is with Vasavi College of Engineering, Hyderabad, Andhra Pradesh, India (e-mail: adilakshmiT.cse@rediffmail.com).

medium is clear, node returns to sleep. Every transmission, to support LPL is preceded by a preamble till the check interval so that the intended receiver is transmission aware and receives incoming packet. This shifts load from receivers to senders, saving much energy during light traffic load.

BMAC's flexible interface allows system parameter reconfiguration on the fly according to network state. It gives control to upper layers. Link-level retransmission is disabled in BMAC default settings. Higher layers enable the schemes when necessary. The idea is to simultaneously facilitate cross-layer optimization and preserve layered architecture.

Understanding nodes mobility pattern is necessary to design realistic models and resource efficient mobility estimation mechanisms. Based on anticipated mobility patterns, protocol design makes plausible assumptions when handling communication handover. All WSNs MAC protocols enable nodes to sleep periodically. Sleeping duration is longer than active duration, the aim being to avoid idle listening and overhearing and to achieve optimal network life.

Many approaches exploit nodes, data collection mobility. These approaches' focus is classified into sink mobility and node mobility. In sink mobility, the sink - the ultimate destination of sensed WSN data moves and routes itself in networks to collect data from static nodes. But, node mobility is more complicated and challenging as individual sensor nodes move from place to place when they attempt to maintain an end-to-end communication link [11].

This study evaluates XMAC and BMAC routing protocol performance under static and mobility scenarios. The rest of the study is as follows: Section II discusses related work; Section III explains the methods used, and section IV discusses the results.

II. Related Works

The first mobility control scheme to improve communication performance in wireless networks presented by [12] is completely distributed, requiring a node to possess only local information. It is self-adaptive, and transparently encompasses many operation modes, each mode improving power efficiency for one unicast flow, multiple unicast flows, and many-to-one concast flows. This ensures extensive evaluation on mobility control feasibility, proving that controlled mobility improves network performance in varied scenarios. This work is a new distributed control networking application where underlying network communication is input to local control rules guiding a system to a global objective. Data propagation optimization using mobility is examined in this paper. It explains mobility as a network control primitive.

A 3-tier architecture that exploits mobile entities random motion like humans or animals to collect information from the sensors and relay it to a central control center was presented by [13]. Kansal et al. [14] performed a small sensor network's experimental evaluation with a mobile entity that moves back and forth on a straight line.

Jea et al. [15] examined multiple mobile entities moving on a line and an algorithm to load balance data collection process assuming full coverage of the network by mobile entities is proposed. Controlled mobility is an active research area; as seen in Luo and Hubaux [16]. Recently much progress was made in designing distributed mobile systems and understanding natural and artificial mobile systems. These studies focus is not network communications. Cortes et al. [17] revealed that mobility can be purposefully controlled to implement network coverage.

Ladd et al. [18] showed that mobility can improve network localization accuracy. Mobility improves and maintains network coverage in DARPA's self-healing minefield project [19]. But, none of these consider routing or power efficiency, two fundamental networking and communications issues.

T-MAC [20] improves S-MAC design by shortening awake period when the channel is idle. Nodes remain awake through the entire awake period in S-MAC even if they neither send nor receive data. T-MAC improves S-MAC by listening to channel for a short while after the synchronization phase, and when no data is received in this window, the node reverts to sleep mode. The node is awake when data is received, till no further data is received, or till awake period ends. T-MAC uses one fifth of the energy used by S-MAC for variable workloads. While this reduces energy use for variable workloads, the gains came at the cost of reduced throughput and increased latency.

S-MAC [21] is an RTC-CTS based, low power MAC protocol that uses loose synchronization between nodes to allow sensor networks duty cycling. The protocol uses three techniques to attain low power duty cycling like periodic sleep, virtual clustering, and adaptive listening. Network nodes wake up periodically, receive and transmit data, and revert to sleep. A node exchanges schedule information and synchronization with neighbors to assure that both node and neighbors wake up concurrently at the start of the awake period. This schedule is adhered to locally, leading to a virtual cluster, which alleviates the need for system-wide synchronization. Nodes that are on the border of two virtual clusters abide by the schedules of both clusters, which maintain connectivity across the network. After exchange of synchronization information, nodes transmit packets using RTS-CTS till the end of the awake period when nodes enter sleep mode.

III. Methodology

BMAC Design

BMAC [22], is a CSMA-based technique developed at the University of California at Berkeley that uses low power listening and a lengthy preamble to ensure low power communication. Nodes have awake and sleep periods. Each node has an independent schedule. When a node wants to transmit, it precedes data packet with a preamble slightly longer than the receiver's sleep period. A node samples the medium during the awake period, and remains awake to receive data when a preamble is detected.

A sender is assured with an extended preamble that at some point during the preamble the receiver will wake, detect the preamble, and remain awake to receive data. BMAC ensures an interface by which an application adjusts sleep schedule to adapt to changing traffic loads. The adaptation method is left to application developer. BMAC exceeds current protocols regarding throughput, latency, and energy consumption in most cases.

BMAC performs well, but suffers from an overhearing problem, and a long preamble dominates energy use. BMAC preamble sampling scheme adjusts an interval where the channel is checked to equal frame preamble size. If the medium is checked every 100 ms, the packet preamble must last 100 ms minimum, for a receiver to detect packets. Upper layers can change the preamble duration, according to application requirements.

BMAC's advantage in WSNs is that it does not use RTS, CTS, ACK, or other control frame by default, but they can be added if necessary. Also, it is a specialized MAC protocol whose implementation is tested in hardware. No synchronization is needed, and protocol performance is tuned by higher layers to meet various applications needs. The disadvantage is that the preamble leads to a large overhead. An example presents 271 preamble bytes to send 36 data bytes. BMAC design is seen in Fig. 1.

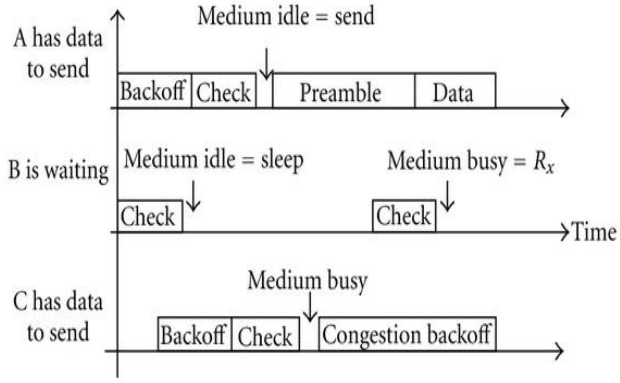

Fig. 1 BMAC Design

XMAC Design

XMAC solves BMAC overhearing using a strobed preamble having a sequence of short preambles before DATA transmission as seen in Fig. 2. In this and similar Figs in this paper, the time period when a node is active is indicated through a solid gray background, node frame reception is indicated by black text on a gray background, and node frame transmission is by white text on a dark background. The target address is embedded in a short preamble, which helps irrelevant nodes to sleep immediately but permits an intended receiver to send an early ACK to sender so that sender stops preamble transmission and starts transmitting a DATA frame immediately. This way, XMAC saves energy avoiding overhearing and reducing latency by half on average. After receipt of a DATA frame, an XMAC receiver stays awake for a time equal to maximum backoff window size to ensure that queued packets are transmitted immediately [23].

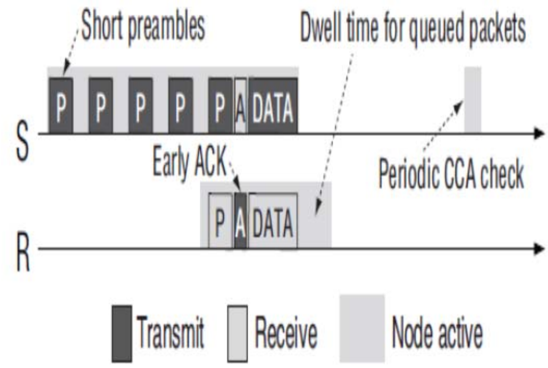

Fig. 2 Operation of XMAC, including the strobed preamble and early acknowledgment

A node does a Clear Channel Assessment (CCA) check during a scheduled wakeup time that is longer than a gap between 2 short preambles. A Unified Power Management Architecture (UPMA) for WSNs package [24] implemented a XMAC variation in TinyOS, where the DATA frame is the short preamble, as seen in Fig. 2. This simplifies implementation and helps senders to determine whether DATA was successfully delivered from receiver's ACK.

The Random Waypoint Mobility Model

Mobility models are building blocks in simulation–based wireless networks studies. A popular and common mobility model is Random Waypoint (RWP) model that is implemented in a networks simulation tools NS–2 [2] and GloMoSim [25] and in performance evaluations of adhoc networking protocols [26], [27]. This mobility model is a straightforward stochastic model describing a mobile network node's movement behavior in a system area as follows:

A destination point ('waypoint') is chosen by a node randomly in the area and moves at a constant speed in a straight line to this point. After waiting for a specific pause time, it selects a new destination and speed, moving with constant speed to this destination. Node movement from a starting position to next destination is represented as one movement period or transition. Destination points are randomly distributed in the system area uniformly.

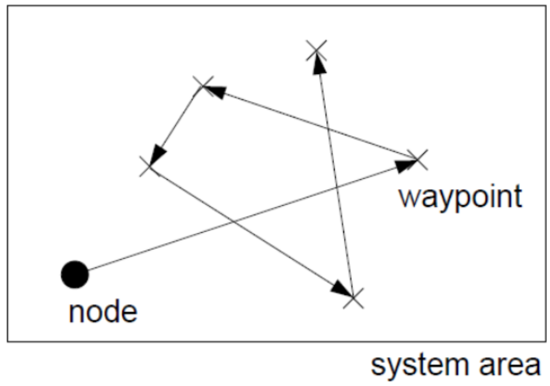

Fig. 3 Illustration of random waypoint movement

In one dimension consider a line segment; in two dimensions consider a rectangular area of size $a \times b$ or a circular area with radius a. For proper nomenclature, many random variables are defined. These are written in upper case letters while specific outcomes are in lower case. Multi–dimensional variables (random coordinates in an area) are written in bold face and scalar variables (random lengths) in normal font. Random waypoint movement is illustrated in Fig. 3.

The parameter j identifies a particular node, and discrete time parameter i denotes the node's movement period. A random variable representing the waypoint's Cartesian coordinates states that node j chooses in its movement period i is denoted by vector *P(j) i*. The movement trace of a RWP node j is formally described as a discrete–time stochastic process, a definition given by selecting a random waypoint *P(j) i* for every movement period i:

$$\left\{ P_i^{(j)} \right\}_{iEN\,0} = P_0^{(j)},\ p_1^{(j)},\ p_2^{(j)}, \ldots.. \tag{1}$$

The waypoints are independently and identically distributed using uniform random distribution over system space A. As every node moves independent of other nodes; it is sufficient to study one node's movement process. Thus, omit index j. Let us consider that a node randomly chooses a new speed Vi for moving from Pi−1 to Pi and a pause time Tp,i at waypoint Pi. A node's complete movement process is given by

$$\{(P_i, V_i, T_{p,i})\}_{iEN} = (P_1, V_1, T_{p,1}), (P_2, V_2, T_{p,2}), (P_3, V_3, T_{p,3}), \ldots. \tag{2}$$

where an additional waypoint P0 for initialization is needed. A sample is denoted by {(pi, vi, τp,i)} i∈N. A movement period i is completely described by a vector (pi−1, pi, vi, τp,i). When referring to one random process variable, omit index i and write P, V, or Tp. The values for pause time are selected from a bounded random distribution fTp(τp) in the interval [0, τp,max] with τp,max < ∞ and a well–defined expected value E {Tp}. Generally, the speed is chosen from a random distribution fV (v) within an interval [vmin, vmax] with vmin > 0 and vmax < ∞ [28].

IV. Experimental Results

In this study BMAC and XMAC protocols are evaluated for WSN at static and various mobility levels. The results are analyzed from the following simulation values. The simulations were conducted to evaluate the performance of BMAC, XMAC protocols under static and dynamic conditions. The RWP mobility model is used and the mobility is varied from 10 Kmph to 40 Kmph. Performance of BMAC and XMAC protocols were evaluated based on the Packet Delivery Ratio (PDR), End to End Delay, Number of hops, and Jitter for various mobility level in WSN.

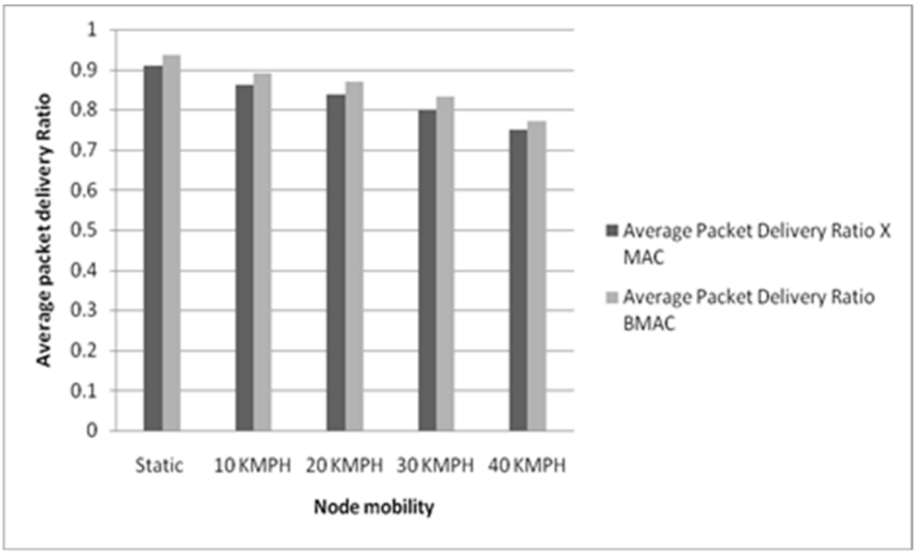

Fig. 4 Packet Delivery Ratio (PDR)

Fig. 4 shows the packet delivery ratio for various mobility, when using BMAC and XMAC protocols. In static WSN, average packet delivery ratio is 0.90 and 0.93 using XMAC and BMAC protocols respectively. Average packet delivery ratio in static is higher when using BMAC protocol than XMAC. With the increase in mobility speed, both BMAC and XMAC protocol has lower average packet delivery ratio value.

Fig. 5 shows the End to end delay for various mobility, when using BMAC and XMAC protocols. In WSNs End to End delay is low when WSN is static, for both BMAC and XMAC protocols. When the mobility level increases both BMAC and XMAC protocol has higher End to End delay value.

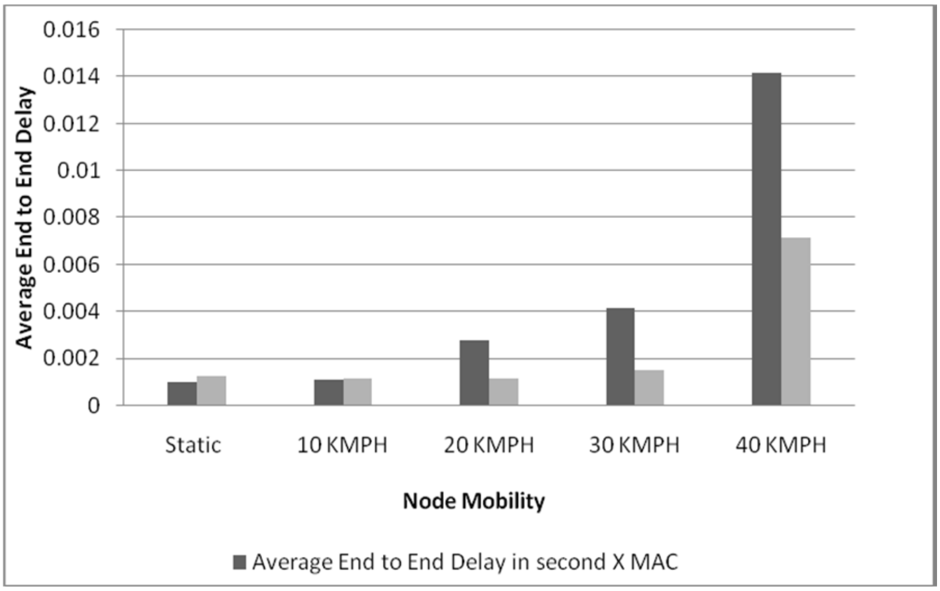

Fig. 5 End to end delay

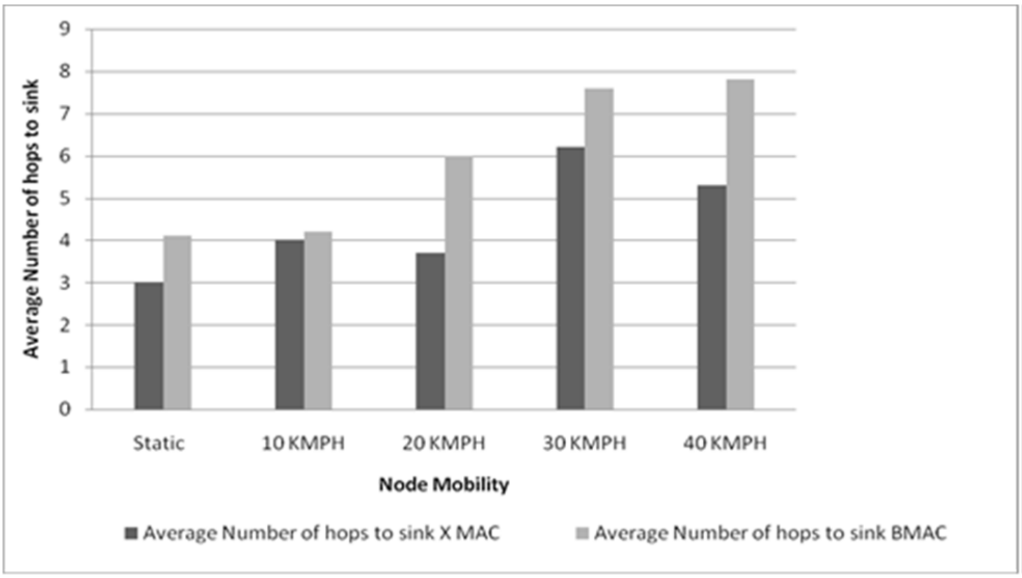

Fig. 6 Number of hops to sink

In WSN, node mobility is directly proportional to the number of hops to sink. Fig. 6 shows the Average number of hops for various node mobility values. At 40 KMPH mobility level, Average number of hops to sink value is increased by 2.3% and 3.7% in XMAC and BMAC respectively when compared to static level.

In WSN, node mobility is directly proportional Jitter. Fig. 7 shows the Jitter for various node mobility values. Both XMAC and BMAC protocols increased jitter value when mobility level increased.

V. Conclusion

This study investigated MAC protocols performance and presented a mathematical analysis of the well–known random waypoint mobility model's stochastic properties. This study evaluated BMAC and XMAC protocols for WSN at static and various mobility levels. A RWP mobility model is used, and mobility varied from 10 Kmph to 40 Kmph. BMAC and XMAC protocols performance were evaluated based on PDR, Number of hops, End to End Delay and Jitter for various WSN mobility levels. The results show that the BMAC achieved better performance compared to XMAC in static and dynamic scenarios. It was observed that high mobility degraded routing performance.

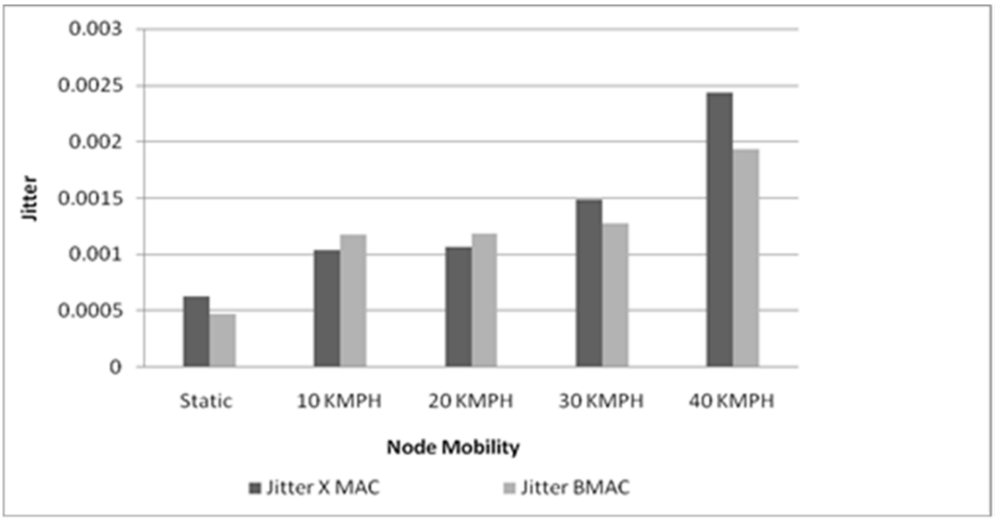

Fig. 7 Jitter

REFERENCES

[1] W. Dargie and C. Poellabauer, Fundamentals of Wireless Sensor Networks: Theory and Practice. Wiley Publishing, 2010.

[2] Demirkol, I., Ersoy, C., & Alagoz, F. (2006). MAC protocols for wireless sensor networks: a survey. Communications Magazine, IEEE, 44(4), 115-121.

[3] R. Szewczyk, J. Polastre, A. Mainwaring, and D. Culler. Lessons from a sensor network expedition. In Proceedings of the First European Workshop on Sensor Networks (EWSN), Jan. 2004.

[4] K. Akkaya and M. Younis, “A Survey of Routing Protocols in Wireless Sensor Networks,” Ad Hoc Network J., vol. 3, no. 3, pp. 325-349, 2005.

[5] Ye, W., Silva, F., & Heidemann, J. (2006, October). Ultra-low duty cycle MAC with scheduled channel polling. In Proceedings of the 4th international conference on Embedded networked sensor systems (pp. 321-334). ACM.

[6] Rajendran, V., Obraczka, K., & Garcia-Luna-Aceves, J. J. (2006). Energy-efficient, collision-free medium access control for wireless sensor networks. Wireless Networks, 12(1), 63-78.

[7] Halkes, G. P., van Dam, T., & Langendoen, K. G. (2005). Comparing energy-saving MAC protocols for wireless sensor networks. Mobile Networks and Applications, 10(5), 783-791.

[8] M. Buettner, G. V. Yee, E. Anderson, and R. Han, “X-MAC: A short preamble mac protocol for duty-cycled wireless sensor networks,” Proc. 4th international conference on Embedded networked sensor systems, pp. 307–320, 2006.

[9] A. El-Hoiydi and J.-D. Decotignie, “Wisemac: an ultra low power mac protocol for the downlink of infrastructure wireless sensor networks,” in Proc. Ninth International Symposium on Computers and Communications 2004 Volume 2 (ISCC”04) - Volume 02, ser. ISCC ’04. Washington, DC, USA: IEEE Computer Society, 2004, pp. 244–251. (Online). Available: http://portal.acm.org/citation.cfm?id= 1126253.1129805

[10] 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,” Proc. 6th ACM

[11] Dong, Q., & Dargie, W. (2013). A survey on mobility and mobility-aware MAC protocols in wireless sensor networks. Communications Surveys & Tutorials, IEEE, 15(1), 88-100.

[12] D. Goldenberg, J. Lin, A. Morse, B. Rosen, and Y. Yang. Towards mobility as a network control primitive. In 5th ACM International Symposium on Mobile Ad-Hoc Networking and Computing (MobiHoc04), 2004.

[13] R. C. Shah, S. Roy, S. Jain, and W. Brunette. Data mules: Modeling a three-tier architecture for sparse sensor networks. In IEEE Workshop on Sensor Network Protocols and Applications (SNPA), 2003.

[14] A. Kansal, A. Somasundara, D. Jea, M. Srivastava, and D. Estrin. Intelligent fluid infrastructure for embedded networks. In 2nd ACM/USENIX International Conference on Mobile Systems, Applications, and Services (MobiSys04), 2004.

[15] D. Jea, A. Somasundara, and M. Srivastava. Multiple controlled mobile elements (data mules) for data collection in sensor networks. In 1st IEEE Conference in DistributedComputing in Sensor Systems (DCOSS05), pages 244–257, 2005.

[16] J. Luo and J.-P. Hubaux. Joint Mobility and Routing for Lifetime Elongation in Wireless Sensor Networks. In 24th IEEE INFOCOM, Miami, USA, 2005.

[17] J. Cortes, S. Martinez, T. Karatas, and F. Bullo. Coverage control for mobile sensing networks: variations on a theme. In Mediterranean Conference on Control and Automation, Lisbon, Portugal, July 9-13 2002.

[18] A. M. Ladd, K. E. Bekris, A. Rudys, L. E. Kavraki, D. S. Wallach, and G. Marceau. Robotics-based location sensing using wireless Ethernet. In Proceedings of The Eighth International Conference on Mobile Computing and Networking (Mobicom) 2002, Atlanta, GA, Nov. 2002.

[19] DARPA. Self-healing minefield. http://www.darpa.mil/ato/programs/SHM/.

[20] T. van Dam and K. Langendoen. An adaptive energyefficient mac protocol for wireless sensor networks. In 1st ACM Conference on Embedded Networked Sensor Systems (SenSys), pages 171–180, 2003.

[21] W. Ye, J. Heidemann, and D. Estrin. An energyefficient mac protocol for wireless sensor networks. In 21st International Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM’02), New York, NY, USA 2002.

[22] J. Polastre, J. Hill, and D. Culler. Versatile low power media access for wireless sensor networks. In The Second ACM Conference on Embedded Networked Sensor Systems (SenSys), pages 95–107, November 2004.

[23] Kevin Klues, Gregory Hackmann, Octav Chipara, and Chenyang Lu. A Component-Based Architecture for Power-Efficient Media Access Control in Wireless Sensor Networks. In Proceedings of the 5th International Conference on Embedded Networked Sensor Systems, pages 59–72, 2007.

[24] J. Broch, D. A. Maltz, D. B. Johnson, Y.-C. Hu, and J. Jetcheva. A performance comparison of multihop wireless ad hoc network routing protocols. In Proc. ACM Intern. Conf. on Mobile Comp. and Netw. (MobiCom), Dallas, TX, Oct. 1998.

[25] Glomosim. http://pcl.cs.ucla.edu/projects/glomosim/, Nov. 2002.

[26] S. R. Das, C. E. Perkins, and E. M. Royer. Performance comparison of two on-demand routing protocols for ad hoc networks. In Proc. IEEE Infocom, Tel Aviv, Israel, 2000.

[27] G. Holland and N. H. Vaidya. Analysis of TCP performance over mobile ad hoc networks. In Proc. ACM Intern. Conf. on Mobile Comp. and Netw. (MobiCom), Seattle, WA, Aug. 1999.

[28] Stochastic Properties of the Random Waypoint Mobility Model Christian Bettstetter (bettstetter@ei.tum.de) Technische Universit¨at M¨unchen, Institute of Communication Networks, 80290 Munich, Germany Hannes Hartenstein, Xavier P´erez–Costa NEC Europe, Network Laboratories, 69115 Heidelberg, Germany

M V Ramana Rao is with University College of Engineering, Hyderabad. He is currently pursuing his doctorate in India.

T. Adilakshmi is currently working in Vasavi College of Engineering, Hyderabad, India.