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IMPACT OF RADIO PROPAGATION MODELS ON A CROSS-LAYER PROTOCOL TO PROVISION QoS IN WIRELESS MULTIMEDIA SENSOR NETWORKS

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ABSTRACT

Wireless multimedia sensor networks (WMSNs) depend upon novel Quality of Service (QoS) protocols for real-time and multimedia applications because of having limited resources and inherent features. In this paper, we examine the impact of radio propagation models, namely Friis Free Space, 2 Ray Ground and Hata Urban, on a cross-layer protocol, XLCP, to offer QoS in Wireless Multimedia Sensor Networks. XLCP, unifying network routing and MAC functionalities, is a cross-layer protocol that enables scalable service differentiation. Performance results indicate that radio propagation models influence QoS level in simulations for XLCP protocol. As far as we know, both exploring the impact of physical layer propagation model on the higher layer protocols and development of physical layer aware protocols are still an unexplored area.

Index Terms: Wireless multimedia sensor networks, multimedia, QoS, radio propagation model.

Introduction

Technological advances in hardware devices such as CMOS cameras and microphones have enabled low cost curtailed embedded sensor devices equipped with video and audio assemble components [1], [2]. Networking such hardware devices gathering multimedia content from physical environment is named as Wireless Multimedia Sensor Networks (WMSNs) [3], [4]. In order to successfully run WMSN applications, a concrete degree of Quality of Service (QoS) guarantees, such as reliable and timely transmission of multimedia content, is expected from the WMSN. QoS describes satisfaction level of application concerns from the underlying communication network or discerned traffic quality level that the underlying network gives to an application. For having constrained resources such as memory, storage, processing and bandwidth, WMSNs indicate considerable QoS provisioning challenge. On the other hand, protocols developed for traditional wireless networks and ad hoc networks are not applicable to WMSNs. Therefore, brand-new generations of protocols are required for WMSNs. Increasing number of WMSN applications, such as mission critical target tracking in battlefields and real-time emergency response will become reality once challenges are tackled.

Traditional layered wireless protocols are inadequate for WMSNs since layered design inherits redundancy and common dependencies exist in different layers. Thus, cross-layer design approaches have emanated to address performance enhancement of WMSN protocols [5], [6]. In order to meet QoS requirements of WMSN applications, cross layer design is very crucial for improving the performance and efficiency of protocols. In our previous studies, we presented a cross-layer communication protocol, XLCP [7] that unifies routing and MAC functionalities and enables scalable service differentiation in order to meet QoS requirements of WMSN applications. XLCP is also tested and confirmed in an image, voice and activity transmission applications [8]–[10].

The performance of a wireless protocol is affected by the underlying radio propagation model. The number of nodes within a collision domain that is a crucial parameter for contention and interference is obtained by the radio propagation model [11]. Consecutively, ability of transmitting a packet to a node is directly affected where QoS metrics, such as reliability, throughput and delay, results in different figures. In this paper, the impact of radio propagation models on XLCP to provision QoS in WMSNs is examined.

Related Work

There is not much research on how radio propagation models impact on the performance of the protocols in wireless multimedia sensor networks (WMSNs). There has been some research in wireless ad hoc networks [11], [12] and sensor networks [13]–[15]. The impact of acoustic propagation models on the higher layer protocols are investigated in the scope of underwater wireless sensor networks [16]. The literature review shows that the influence of propagation models on the performance of the WMSN are not investigated deeply yet. This gap within the research inspired this work.

XLCP: A Xross-Layer Communication Protocol for Service Differention

XLCP unifies MAC and Routing protocol functionalities into a single module [7]. XLCP is a fairly simple protocol because of resource limitation of sensor nodes. It is completely stateless, based on localized packet forwarding, and assumes location awareness. Each node is required to find out its location relative to sink. Localized packet forwarding decisions are determined by a cost function leveraging feedback on the level of energy, data rate, channel quality and available buffer length in order to determine the best next hop. During CSMA/CA-like MAC operation, nodes randomly access to channel. XLCP also utilizes back-off interval, inter frame spacing and MAC frame retransmission counts. By differentiating such parameters and utilizing the cost function, QoS (i.e. reliability, throughput, delay, reliability, or combinations) differentiation is achieved.

Every sensor nodes achieve distributed duty cycling. First of all, all sensor nodes reside in IDLE state where they listen to the communication channel. Upon detecting a communication over the channel, o sensor node sets the channel busy until timer expires. Whereas a packet associated to class Q is determined and the channel is available, a sensor note sets itself to RTSI state to send an RTS-I packet. During RTSI state, the $CSMA_{RTSI}$ algorithm similar to CSMA/CA method with parameter values depending upon QoS class of the packet is applied by a sensor node. RTS-I packets are investigation packets to determine the quality level of the next forwarding node. Such different QoS parameters results with service differentiation. Subsequently, a sensor node broadcasts an RTS-I packet and it transfers into WCTSQ state to receive for a CTS-Q packet. Then, it collects all CTS-Q packets associated with the packet for $WCTSQ^{Q}$ period.

When a sensor node receives a broadcast RTS-I packet, the sensor node transfers into CTSQ state and determines the QoS-cost value that will be inserted into unicast CTS-Q packet provided that the sensor node is in IDLE state and is closer to sink within a given threshold. The QoS-cost value is determined by a cost function based on SNR, remaining energy, data rate and buffer length. CTS-Q packets carry out quality level of a node, cost value, computed by a cost function. Cost value is used as one-hop feedback control in routing decisions. During CTSQ state, the sensor node performs $CSMA_{CTSQ}$ algorithm akin to CSMA/CA approach with parameter values assigned to QoS class of the packet.

The sensor node collects the CTS-Q packets during $WCTSQ^{Q}$ period to select the best candidate node that send the highest QoS-cost value in CTS-Q packet to transmit the data packet by getting into DATA state. In DATA state, the sensor nodes send the data packet to a relay node that transmitted the highest QoS-cost value injected into CTS-Q packet. In order to send data packet to candidate relay node, sensor node applies $CSMA_{DATA}$ algorithm. Immediately, if acknowledgement is enabled, the sensor node gets into WACK state to receive an acknowledgement packet. Otherwise, it gets into IDLE state. When a sensor node receives a packet, it updates received SNR value of related packet by applying exponential weighted moving average.

Radio Propagation Models

We examine the impact of radio propagation models, Friis Free Space, 2 Ray Ground and Hata Urban, on a cross-layer protocol, XLCP, to provision QoS. For Friis, the received power by an antenna in dBm is given as:

$$Pr = Pt + Gt + Gr - (32.46 + 20 * \log_{10} B + 20 * \log_{10} d) \qquad (1)$$

where B is in mega hertz, and d is in kilo meters.

For 2 Ray Ground, the received power by an antenna in dBm is given as:

$$Pr = Pt + Gt + Gr - (20 * \log_{10} 50 + 20 \log_{10} 1.5 - 40 * \log_{10} d) \qquad (2)$$

where d is in meters.

For Hata Urban, the received power by an antenna in dBm is given as:

$$PL_{11} = (1.1 * log_{10}B - 0.7) * 1.5 - (1.56 * log_{10}B - 0.8) \quad (3)$$

where d is in meters.

$$PL_1 = 69.55 + (26.16 * log_{10}B - (13.82 * log_{10}50) - PL_{11}) \quad (4)$$

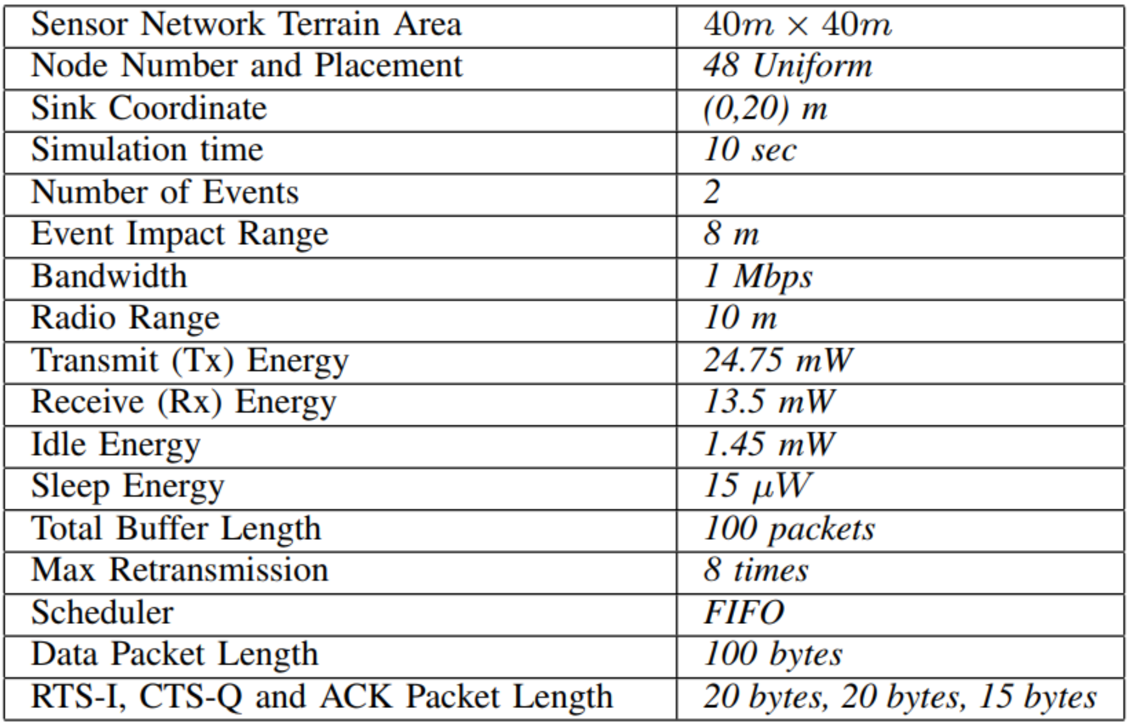
$$PL_2 = 44.9 - 6.55 * log_{10}50 \quad (5)$$

$$Pr = Pt + Gt + Gr - (PL_1 + PL_2) \quad (6)$$

where B is in mega hertz.

Performance Evaluation

In sequence to gain insights on the impact of radio propagation models on XLCP protocol, we carried out detailed simulations on an in-house developed simulator in Matlab environment [17]. The NS-2 simulator [18], [19] is used as a reference for implementing XLCP in Matlab language. Table I represents the general simulation environment parameters.



Sensor Network Terrain Area	$40m \times 40m$
Node Number and Placement	*48 Uniform*
Sink Coordinate	*(0,20) m*
Simulation time	*10 sec*
Number of Events	*2*
Event Impact Range	*8 m*
Bandwidth	*1 Mbps*
Radio Range	*10 m*
Transmit (Tx) Energy	*24.75 mW*
Receive (Rx) Energy	*13.5 mW*
Idle Energy	*1.45 mW*
Sleep Energy	*15 μW*
Total Buffer Length	*100 packets*
Max Retransmission	*8 times*
Scheduler	*FIFO*
Data Packet Length	*100 bytes*
RTS-I, CTS-Q and ACK Packet Length	*20 bytes, 20 bytes, 15 bytes*

Table I: WSMN Simulation Parameters

$\beta^{all-Q}_{dury-cycle}$	*1*
$\beta^{Q}_{minNB-x}$	*4*
$\beta^{Q}_{maxNB-x}$	*10*
$\beta^{Q}_{minBE-x}$	*3*
$\beta^{Q}_{maxBE-x}$	*8*
$\beta^{Q}_{minCW-x}$	*1*
$\beta^{Q}_{snr-x-c}$	*0.2*
$\beta^{Q}_{ACK-enable}$	*TRUE*

Table II: Simulation Parameters used in XLCP (X=rtsi, ctsq, data, ack)

In simulations, 48 sensor nodes are randomly deployed in a 40m×40m sensor network field. It is presumed that the nodes and sink are stationary and the network does not have any vacated region. Constantly, the sink is located at coordinates (20,0)m. In each simulation, concurrently, 2 events occur. At coordinates (10,30)m, the first event is fired up and at coordinates (30,30)m, the second event is fired up. The impact of an event is 8m. Figure 1 represents an example sensor network topology.

Only 2 QoS classes are specified in simulations. Source sensor nodes around the impact range of the events generate data packets to be delivered to the sink node. In other words, 2 event packets are generated at each certain period around the event impact range. If a sensor node has not got available buffer, it drops the generated or forwarded packets. Substantial XLCP parameters for both Q=1 and Q=2 QoS classes are presented at Table II. Duty-cycling is not applied in simulations ($\beta^{all-Q}_{duty-cycle} = 1$). In all simulations, it is assumed that the channel has constant bit error rate (BER) of 10^{-8}. Each simulation is run for 10 sec. Moreover, the average of 5 trials is run with different network topologies to evaluate the performance of simulations. In simulations, related XLCP parameters are conformed to the IEEE 802.15.4 parameters. Unless otherwise specified, all simulations are rigorously run with these parameters.

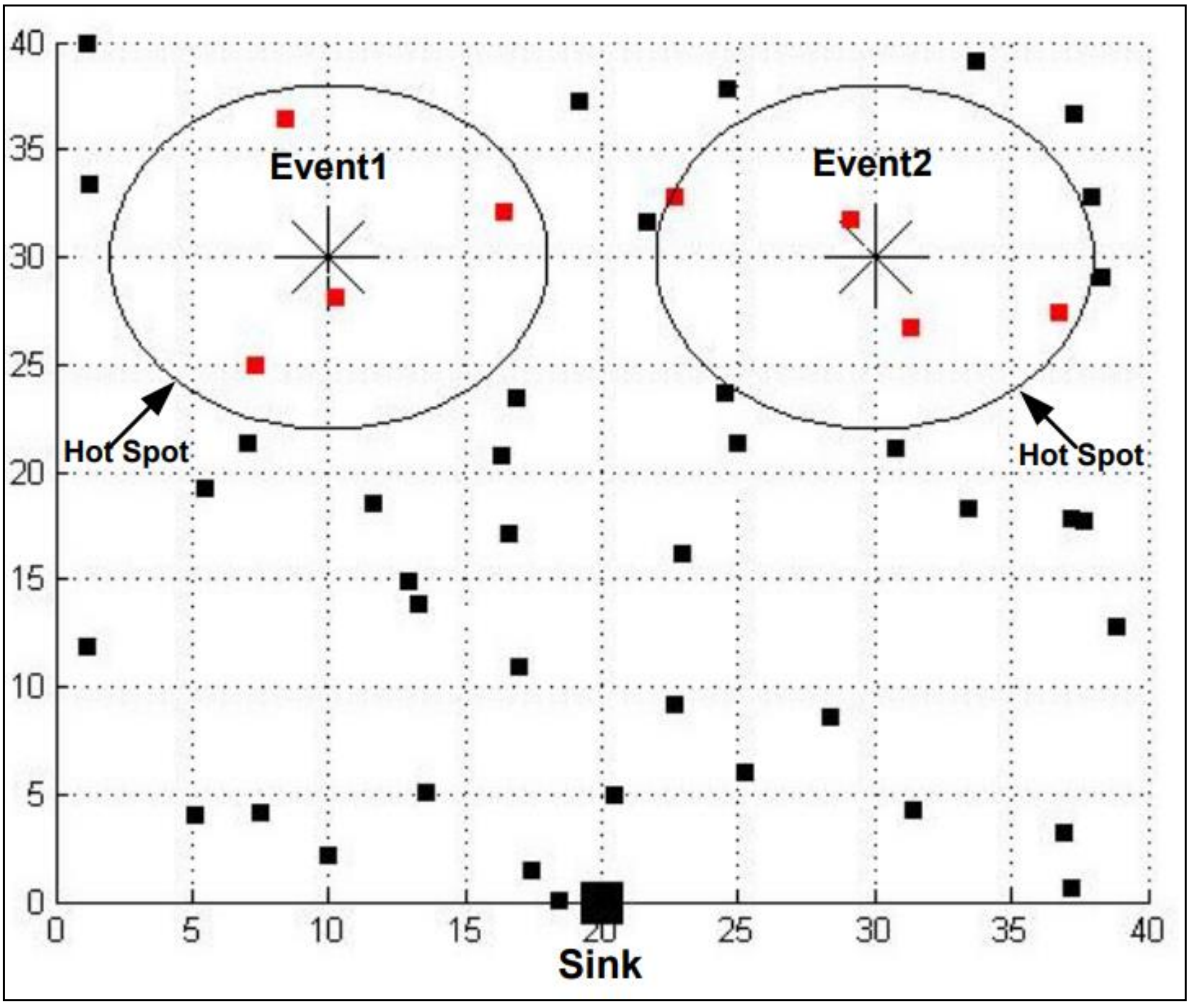
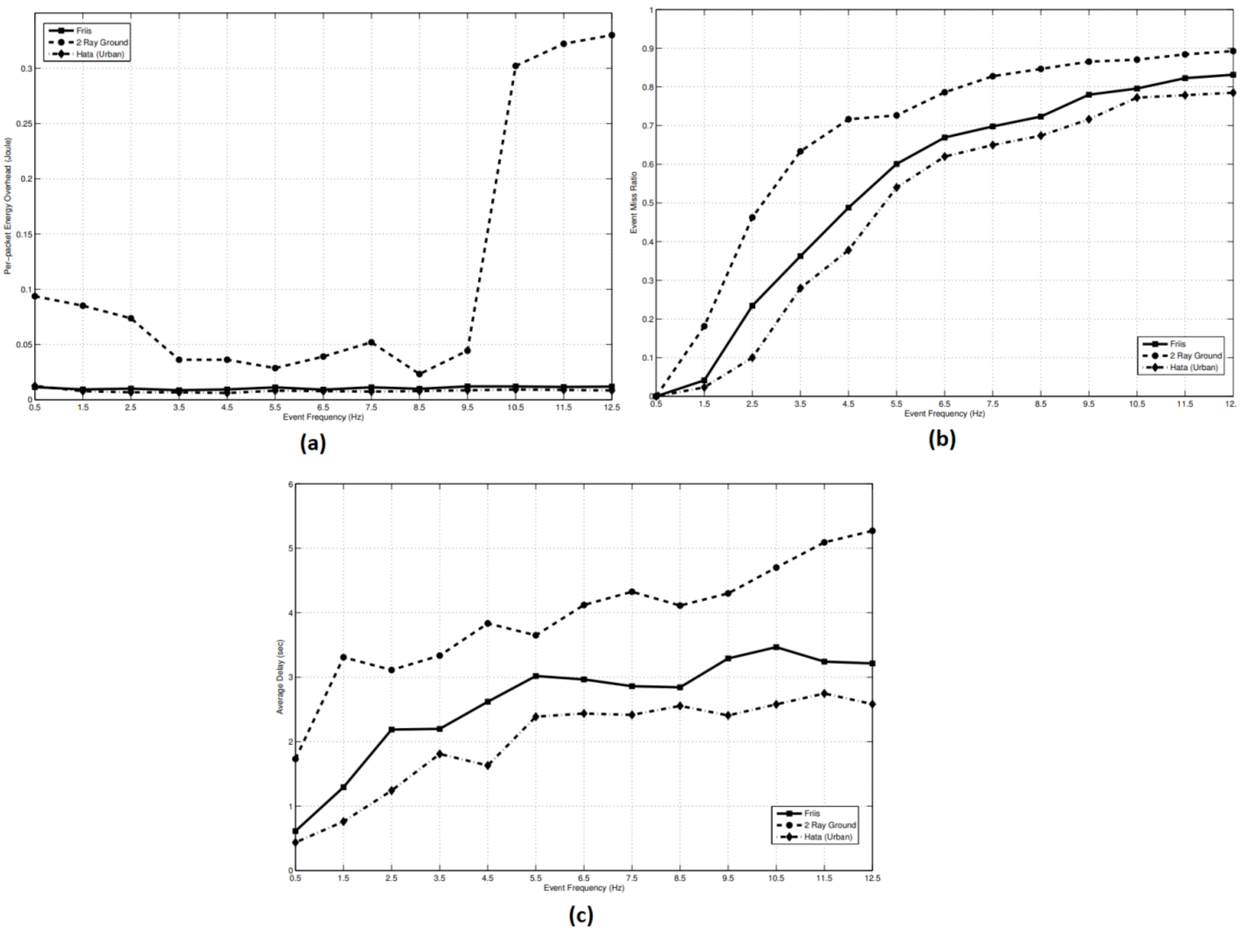


Fig. 1: An Example Sensor Network Topology

We explored the subsequent QoS performance metrics in performance evaluation:

- *Per-packet Energy Overhead:* This metric represents the consumed total energy of a unique data packet received at the sink.
- *Event Miss Ratio:* This metric represents the proportion of total lost data packets to total generated event data packets.
- *Average Delay:* This metric represents the average of end-to-end time delay of all data packets received at sink.
- *Event Reliability:* This metric represents the proportion of total received unique data packets at the sink to total number of generated data packets at source sensor nodes.
- *Sensed Event Reliability:* This metric represents the proportion of total received unique data packets at the sink to total number of generated and placed into the buffer of a source node data packets at source sensor nodes.
- *Throughput* is the number of bits received at the sink per second.

In Figure 2 Per-packet Energy Overhead, Event Miss Ratio and Average Delay graphics are presented. For Per-packet Energy Overhead in Joules, Friis and Hata Urban radio propagation models show similar linear constant function behavior.

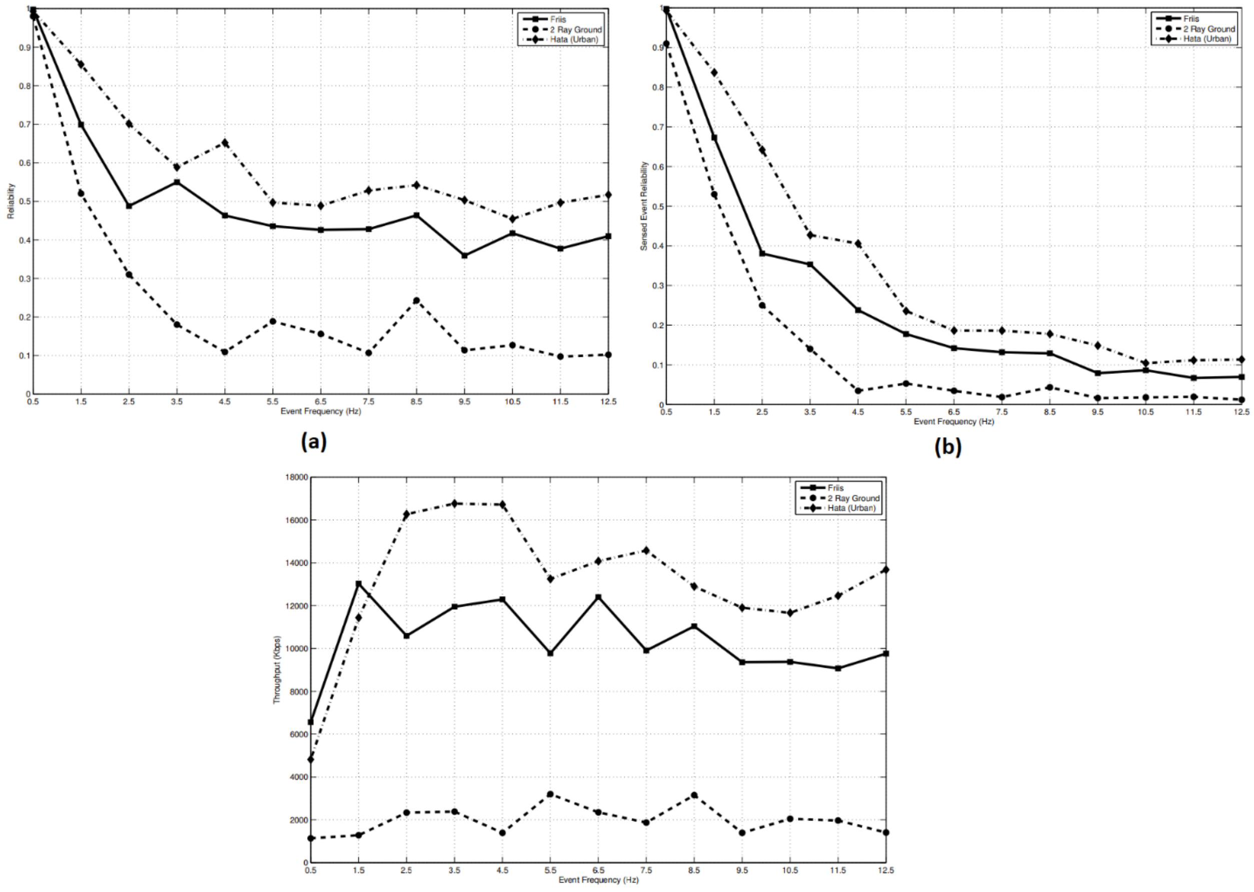


(a) (b) (c)

Fig. 2: Per-packet Energy Overhead, Event Miss Ratio and Average Delay Graphics

For Friis and Hata Urban radio propagation models, increasing event frequency do not change Per-packet Energy Overhead. Hata Urban results with slightly lower Per-packet Energy Overhead than that of Friis. 2 Ray Ground radio propagation model shows variable function behavior for Per-packet Energy Overhead. It is obvious that when event frequency increases, Event Miss Ratio also gets increased. All Event Miss Ratio graphics are exponential up to a certain event frequency, and then logarithmic. However, Hata Urban radio propagation model results with lower Event Miss Ratio than that of Friis and 2 Ray Ground models. And, 2 Ray Ground radio propagation model results with the highest Event Miss ratio. It is clear that when event frequency increases, Average Delay also gets increased gradually. All Average Delay functions are in part logarithmic. Hata Urban radio propagation model results with lower Average Delays than that of Friis and 2 Ray Ground models. And, 2 Ray Ground radio propagation model results with the highest Average Delay.

In Figure 3, Reliability, Sensed Event Reliability and Throughput graphics are presented. For Reliability, Friis, 2 Ray Ground and Hata Urban radio propagation models show similar negative exponential function behaviour. Hata Urban results with the best Reliability, and 2 Ray Ground results with the worst Reliability. Friis, 2 Ray Ground and Hata Urban radio propagation models



(a)

(b)

(c)

Fig. 3: Reliability, Sensed Event Reliability, Throughput Graphics

show similar negative exponential function behavior for Sensed Event Reliability. Hata Urban results with the best Sensed Event Reliability, and 2 Ray Ground results with the worst Sensed Event Reliability. For Throughput, again, 2 Ray Ground ends up with the worst results, and Hata Urban ends up with the best results.

Conclusion

Evaluating performance of the protocols on top of physical layer propagation models is a frequently neglected research area in WMSN. However, accurate knowledge of propagation models assists the progress of more efficient, effective and robust network protocols. This study investigates the effect of propagation model on the performance of a XLCP communication protocol that is developed for the needs of WMSNs. The simulations show that physical layer propagation model impacts the performance of XLCP. This implies that superior protocols can be designed while considering physical layer propagation model.

REFERENCES

[1] S. Soro and W. Heinzelman, "A survey of visual sensor networks," *Advances in Multimedia*, vol. 2009, 2009.
[2] Y. Charfi, N. Wakamiya, and M. Murata, "Challenging issues in visual sensor networks," *Wireless Communications, IEEE*, vol. 16, no. 2, pp. 44–49, 2009.
[3] I. F. Akyildiz, T. Melodia, and K. R. Chowdhury, "A survey on wireless multimedia sensor networks," *Computer Networks*, vol. 51, no. 4, pp. 921–960, 2007.
[4] I. Almalkawi, M. Guerrero Zapata, J. Al-Karaki, and J. Morillo-Pozo, "Wireless multimedia sensor networks: current trends and future directions," *Sensors*, vol. 10, no. 7, pp. 6662–6717, 2010.

[5] T. Melodia, M. Vuran, and D. Pompili, "The state of the art in cross-layer design for wireless sensor networks," *Wireless Systems and Network Architectures in Next Generation Internet*, pp. 78–92, 2006.

[6] L. Mendes and J. JPC Rodrigues, "A survey on cross-layer solutions for wireless sensor networks," *Journal of Network and Computer Applications*, vol. 34, no. 2, pp. 523–534, 2011.

[7] A. K. Demir, H. E. Demiray, and S. Baydere, "Qosmos: cross-layer qos architecture for wireless multimedia sensor networks," *Wireless networks*, vol. 20, no. 4, pp. 655–670, 2014.

[8] A. K. Demir, K. Irgan, H. E. Demiray, and S. Baydere, "Transmitting objects in images with service differentiation based source coding in wireless sensor networks," in *International Wireless Communications and Mobile Computing Conference (IWCMC), 2013 9th*. IEEE, 2013.

[9] A. K. Demir, O. Turkes, and S. Baydere, "Differentiating emergency voice traffic in indoor wireless activity monitoring network," in *IEEE 10th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*. IEEE, 2014, pp. 598–603.

[10] G. Uslu, B. Sebnem, and A. K. Demir, "On the network packet loss tolerance of svm based activity recognition," in *XIII International Conference on Health Informatics*, 2015.

[11] E. Van Eenennaam, "A survey of propagation models used in vehicular ad hoc network (vanet) research," *Paper written for course Mobile Radio Communication, University of Twente*, vol. 46, 2008.

[12] A. Rhattoy and A. Zatni, "The impact of radio propagation models on ad hoc networks performances," *Journal of Computer Science 8 (5): 752-760, 2012.*, 2012.

[13] Z. Gao, W. Li, Y. Zhu, Y. Tian, F. Pang, W. Cao, and J. Ni, "Wireless channel propagation characteristics and modeling research in rice field sensor networks," *Sensors*, vol. 18, no. 9, p. 3116, 2018.

[14] A. M. Aldosary, "The impact of different propagation environments on the performance of wireless sensor networks," Ph.D. dissertation, 2017.

[15] S. Kurt and B. Tavli, "Path-loss modeling for wireless sensor networks: A review of models and comparative evaluations." *IEEE Antennas and Propagation Magazine*, vol. 59, no. 1, pp. 18–37, 2017.

[16] J. Llor and M. P. Malumbres, "Underwater wireless sensor networks: how do acoustic propagation models impact the performance of higher-level protocols?" *Sensors*, vol. 12, no. 2, pp. 1312–1335, 2012.

[17] Mathworks, "Matlab," Website, last checked: 14.04.2015. [Online]. Available: http://www.mathworks.com/

[18] K. Fall and K. Varadhan, "The network simulator (ns-2)," Website, last checked: 01.10.2012. [Online]. Available: http://www. isi. edu/nsnam/ns [19] S. McCanne, S. Floyd, K. Fall, K. Varadhan *et al.*, "Network simulator ns-2," 1997.