Enabling QoS in the Internet of Things

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***Abstract*—With the emergence of the Internet of Things (IoT), it is necessary to define service models, which can categorize IoT applications and determine the Quality of Service (QoS) factors necessary to satisfy the requirements of those services. On the other hand, as Wireless Sensor Networks (WSN) constitute a main component of the IoT, they become a key factor concerning QoS provision. In this perspective, we focus our analysis on the possible WSNs integration approaches in the IoT while providing QoS and which best practices to adopt. Furthermore, regarding QoS requirements, we also define service models for the IoT and expose their feasibility through a categorization of IoT applications.**

Keywords-Internet of Things; Wireless Sensor Network; QoS; Service Models; MAC

I. INTRODUCTION

The Internet of Things (IoT) will likely be one of the most important technological breakthroughs of the years to come. IoT could be conceptually defined as a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network [1].

In the IoT, smart things/objects are active participants in business, information and social processes where they are enabled to interact and communicate among themselves and with the environment by exchanging data and information sensed about the environment, while reacting autonomously to the real/physical world events and influencing it by running processes that trigger actions and create services with or without direct human intervention [1]. In this perspective, it is necessary to define service models, which can categorize IoT applications and then determine which Quality of Service (QoS) factors are necessary to satisfy the requirements of those services.

Smart objects are lightweight devices with a sensor or actuator and a communication device. These devices are capable of sensing various types of incidents/parameters and communicating those with other devices. They can be battery-operated, and typically have three components: a CPU (8, 16 or 32-bit microcontroller), memory (a few tens of kilobytes) and a low-power wireless communication device (from a few kilobits/s to a few hundreds of kilobits/s). The size of these devices is very small [2][3]. These devices can work together, forming for example a wireless sensor network (WSN). As a main component of the IoT, WSNs become a key factor concerning QoS provision and therefore should be integrated in the IoT in the best possible way.

In this paper, based on the analysis of the current QoS MAC solutions in WSNs and simulation results, we focus our QoS analysis on the possible WSNs' integration approaches in the IoT. Then, regarding QoS requirements, we also define service models for the IoT and expose their feasibility through a categorization of IoT applications.

The remainder of this article is organized as follows. Section II focuses on a review of current QoS MAC solutions in WSNs. In Section III, we provide a summary of different service models and performance analysis of the IEEE 802.15.4 from [4]. The fourth Section describes a WSN integration approach in the IoT providing QoS. Then we propose best practices to adopt when using the IEEE 802.15.4 protocol for WSNs while providing the aforementioned service models. In the Section V, we extend the service models described in Section III to the IoT and we present a categorization of IoT applications according to them. Finally, conclusions are presented in Section VI.

II. MAC SOLUTIONS FOR QOS IN WSNS

Many aspects of WSNs such as routing, preservation of battery power and topology control have been studied in previous papers [5], [6], [7]. However, the area of QoS in WSNs remains largely open. The main reason is that WSNs are quite different from traditional wired and wireless networks from several points of view (e.g. energy, processing and memory constraints, heterogeneous and unevenly distributed traffic, network's dynamic changes and scalability problems).

In the following paragraphs, a summary of current QoS-aware MAC solutions for WSNs is provided. Two complete surveys of QoS-Aware MAC protocols and Real Time (RT) QoS support can be found in [8] and [9] respectively. The main characteristics of each protocol are described below:

1) Implicit prioritized access protocol (I-EDF) [10] *and dual-mode MAC protocol* [11]: they adopt a cellular backbone network and thus they are topology-dependent. They use Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA) to guarantee bounded delay (HRT). Energy efficiency is not considered.

2) PEDAMACS [12]: this TDMA-based protocol that aims to achieve both energy efficiency and delay guarantee

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TABLE I. A COMPARISON OF MAC PROTOCOLS

Name	MAC type	RT type	Topology dependent	Energy efficient	Scalability
I-EDF, Dual-mode MAC	FDMA-TDMA	HRT	Cell structure	N/A	Moderate
PEDAMACS	TDMA	HRT	No	High	Low
IEEE 802.15.4	Slotted CSMA/CA, GTS	Best effort/HRT	No	Moderate	Good
Saxena et al.	CSMA	Best effort /Low-Latency	No	High	Good
PQ-MAC	TDMA /CSMA	Best effort/Low-Latency	No	Moderate	Low
I-MAC	TDMA /CSMA	Best effort/Low-Latency	No	High	Moderate
Diff-MAC	CSMA	Best effort /Low-Latency	No	Moderate	Good
EQ-MAC	TDMA /CSMA	Best effort/Low-Latency	1-hop cluster based	High	Moderate
Suriyachai et al.	TDMA	HRT	Data gathering tree	Moderate	Low

(HRT). However, in order to accomplish this, it requires powerful access point (AP). This requirement has reduced its practical application and attractiveness.

3) *IEEE 802.15.4 standard* [13]: it basically uses CSMA/CA. In the beacon-enabled synchronized mode, it provides guaranteed time slots (GTS) and thus, in this case, HRT. It also provides energy saving.

4) *Saxena et al.* [14]: the autors propose a CSMA/CA protocol designed to support three types of traffic: streaming video, non-real-time and best effort. The device adjusts the duty cycle depending on the dominating traffic received in order to achieve energy saving.

5) *PQ-MAC* [15]: it uses both CSMA and TDMA. Energy saving is handled by an advanced wake up scheme, while prioritization is handled by a doubling scheme for high priority data.

6) *I-MAC* [16]: this protocol is based on Z-MAC [17] and defines three priority levels. It uses both CSMA and TDMA.

7) *Diff-MAC* [18]: it is a CSMA/CA based protocol, which provides differentiated services and hybrid prioritization very useful in multimedia applications. Its dynamic adaptation brings higher complexity.

8) *EQ-MAC* [19]: it uses both CSMA and TDMA. It achieves good energy saving and provides service differentiation but only works for bluster based single hop networks and cannot handle multi-hop transmissions.

9) *Suriyachai et al.* [20]: it is a TDMA based protocol, which can provide deterministic bounds for communication between two devices. Although, as it is based on a data gathering tree, its scalability is quite low.

Table II summarizes the QoS support and the major differences of the 10 protocols described in this section.

III. SERVICE MODELS AND PERFORMANCE EVALUATION OF IEEE 802.15.4

A complete description of service models and performance evaluation of the IEEE 802.15.4 standard is presented in [4]. In this section, we provide a summary of this analysis.

A. Service Models

The three service models are based on three factors: interactivity (yes/no), delay (Non Real-Time, Soft Real Time (SRT) and Hard Real Time (HRT)) and criticality (yes/no). The first model is the Open Services Model. It is interactive as it is based on user's queries, non-RT and non mission-critical. The second model is the Supple Services Model. This model is sometimes interactive, sometimes not, depending on the user's subscription, it is SRT and mission-critical. The third model is the Complete Services model. It is not interactive as there is a continuous flow of data, it is SRT or HRT depending on the application and is mission-critical.

B. IEEE 802.15.4 Performance Analysis

In order to provide the services described above in a WSN, we want to be able to provide services, which includes both best effort and HRT, to take into account energy saving while not being dependent of a certain topology in order to offer a solution practically applicable. From this perspective, we can conclude that the 802.15.4 standard offer the best compromise of the aforementioned characteristics and in this optic, the following performance analysis was conducted [4].

The simulations were performed with ns-2 simulator [21], using the IEEE 802.15.4 extension developed at City College of New York [22].

In our simulations we consider an 802.15.4 wireless network with one PAN coordinator and N reduced-function devices, with the nodes located close in a communication distance of 25 meters. This assumption prevents hidden terminal problem which results in data collisions. Wireless nodes are organized in star and random topologies (Fig. 1).

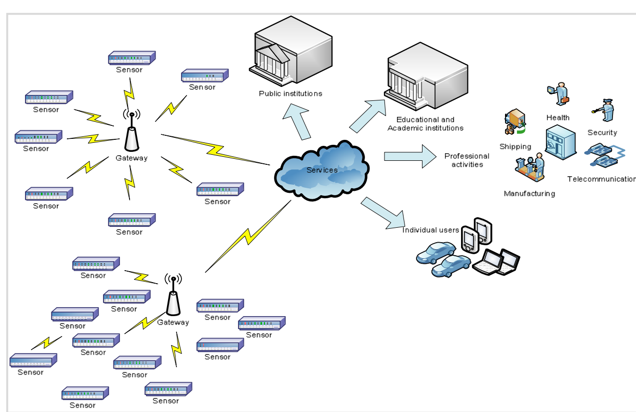

Figure 1. Simulation topologies (Adopted from [4]).

TABLE II. TRAFFIC PARAMETERS (ADOPTED FROM [4])

Parameter	Single user category		Multiple user categories	
Service Type	No Guaran-tees	Mobile Services	No Guarantees - Guarantees	Real-time - Guarantees
Traffic Type	Poisson	Constant Bit Rate (CBR)	Poisson – File Transfer Protocol (FTP)	Constant Bit Rate (CBR) – File Transfer Protocol (FTP)
Number of Nodes	25, 50, 100		25, 50, 100	
Number of Flows	1/4, 1/2, 3/4 and 4/4 number of nodes		¼ Poisson – ¾ FTP	¼ CBR – ¾ FTP
			½ Poisson – ½ FTP	½ CBR – ½ FTP
			¾ Poisson – ¼ FTP	¾ CBR – ¼ FTP
Node Position	Star / Random		Star / Random	
Traffic Direction	Node to Coordinator		Node to Coordinator	
Packet Size	40 Bytes		40 Bytes	20 Bytes – 40 Bytes

Traffic flows are generated in one-hop transmitting data directly to the coordinator, either in distributed or constant bit rate depending on the simulation model. Moreover, for each model, we distinguish two categories: no traffic differentiation (Single User) and traffic differentiation (Multiple User). A summary of traffic characteristics are presented in Table II. Additionally, multi-hop scenarios are evaluated in the random topology. Each simulation runs for 500 s and 15 times.

1) Single User Category: In a star topology with no guarantees, the power consumption does not exceed 0.35 and the worst case limit reaches 80% in packet delivery ratio for a loaded network. In a star topology with mobile services, better performance metrics are achieved: 2.5 times greater throughput and 5% better packet delivery ratio. In a random topology with no guarantees, we have better network performances compared to the star topology: 83% better in power consumption and doubled network lifetime. In a random topology with mobile services, the network behavior is similar compared to the star topology and better performance metrics are achieved: 17% greater throughput, 40% lower average delay and 75% lower power consumption.

2) Service Differentiation for Multiple User Categories: In a star topology, a grade of service differentiation can be achieved with packet delivery ratio reaching 87% and 83% for non guaranteed/guaranteed services and 83% for RT and guaranteed services respectively. There is no difference in throughput and average delay between the classes of services. In a random topology, there are no major discrepancies in network behavior. The throughput is 30% greater and average delay is 6% better compared to star topology metrics. The power consumption is reduced by about 80% compared to a large scaled star network.

3) Priority Based Service Differentiation: Provision of multi-level priority based services by tuning properly the size of the CW. In a star topology, priority services can be achieved with the throughput metric ranging from 4% to 20% depending on the service differentiation provided and the network load. Affected by the same factors, energy consumption ranges between 0.6% and 15%. The worst case in packet delivery ratio reaches 85% of successful delivery. In a random topology, a better delivery ratio is achieved and the gain in power consumption reaches 72%.

IV. WSNS INTEGRATION APPROACH IN THE IOT PROVIDING QOS AND BEST PRACTICES

A. WSNs Integration Approach in the IoT Providing QoS

In fact, one of the most important components in the IoT paradigm is WSN. The benefits of connecting both WSN and other IoT elements go beyond remote access, as heterogeneous information systems can be able to collaborate and provide common services. However, deploying WSNs configured to access the Internet raises novel challenges, which need to be tackled before taking advantage of the many benefits of such integration.

There are a lot of approaches to connect WSNs to the Internet. According to [23] and [24] the most effective, flexible and scalable approach is inspired for current WLAN structure and forms a dense 802.15.4 access point network, where multiple sensor nodes can join the Internet through the network's gateway (Fig. 2).

With gateways acting only as repeater and protocol translators, sensor nodes are also expected to contribute to QoS management by optimizing the resource utilization of all heterogeneous devices that are part of the future Internet of Things.

B. Proposed Best Practices

From Figure 3 [4] and the analysis presented in Section III, we can suggest some best practices about topology and traffic type, based on each application's priorities concerning quality factors.

If nor differentiation of traffic neither a strict delay bound is to be provided, the best topology is the random topology as it assures much better energy saving (83%), throughput (19%) and packet delivery ratio (6%) than the star topology. This approach mostly fits the Open Services model and in some cases the Supple Services model and Complete Services model.

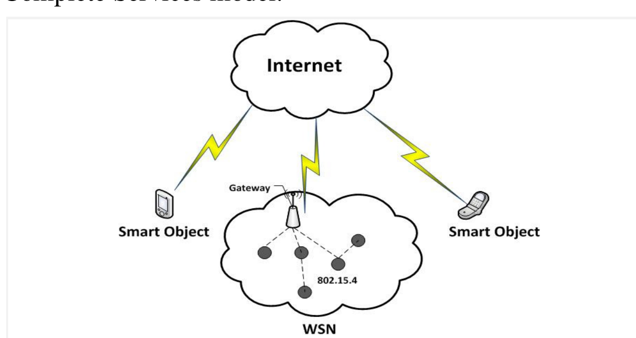

Figure 2. Integration of WSN in the IoT.

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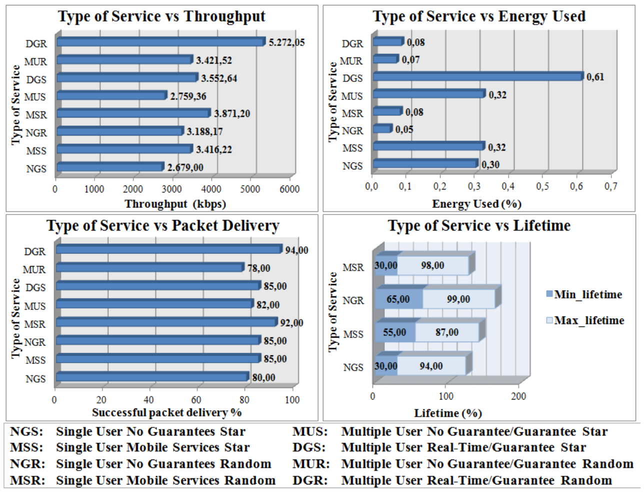

Figure 3. Simulation models statistics for traffic parameters described in Table II (Adopted from [4]).

On the other hand, in order to support RT applications without traffic differentiation, the star topology achieves better delay than the random topology, but as mentioned above, costs more energy (75%). This could be the case while providing Complete Services model.

When different types of traffic are required, as for the two previous cases, again the star topology consumes dramatically much more energy (Non-RT: 78% and RT: 86%) than the random topology and performs worse in terms of throughput (Non-RT: 24% and RT: 48%) and delivery ratio (RT: 10%). This scenario is more likely to fit the Supple Services Model and the Complete Services model.

We can conclude that the only reason to use the star topology is when no other topology is feasible with the specific lightweight devices or when the delay provided by the random topology is not satisfactory. Again, this could be the case while providing Complete Services model when traffic differentiation is required.

V. APPLICATIONS AND SERVICE MODELS IN THE IOT

In [25], the authors present numerous applications made possible by the IoT. Each of these applications has different requirements in terms of QoS. Based on the three service models for WSNs described in Section III, we extend those services to the IoT and demonstrate their feasibility categorizing the applications described in [25] according to these services' characteristics.

In the next paragraphs, for each domain of application described in [25], that is to say Transportation & Logistics, Healthcare, Smart environment, Personal & Social and Futuristic, we categorize each specific application in one of the three services based on their characteristics.

A. Transportation & Logistic

1) Logistics: this is either interactive or non-interactive, in many cases it requires a SRT guarantee and is mission-critical, thus it belongs to the Supple Services model.

2) Assisted driving: this is obvious that this application is mission-critical and requires a continuous flow of data with HRT guarantee, for these reasons it can ben classified into the Complete Services model.

3) Mobile ticketing: if the application's purpose was only to provide information about transportation services, it would be classified into the Open Services model as it is interactive, without requirements of synchronous data. As the oportunity to buy the related tickets is provided, it belongs to the Supple Services model as there is a need of SRT guarantee and the application is now mission-critical.

4) Monitoring environmental parameters: the application is non RT or SRT, it provides periodically collected data and thus is not interactive and is mission-critical as this will influence the measures to be taken. This application can be classified in the Supple Services model.

5) Augmented maps: this application belongs to the Open Services model as it is based on interaction, doesn't require RT and isn't mission-critical.

B. Healthcare

1) Tracking: requiring a continuous flow of data, SRT or HRT guarantees and being mission-critical, this application is another example of a Complete Services model's application.

2) Identification and authentication: this application is interactive, it requires no RT or only SRT guarantees but the security provided makes it mission-critical. Therefore, the application belongs to the Supple Services model.

3) Data collection: interactive or not, it requires a SRT guarantee and is mission-critical. The application can be classified into the Supple Services model.

4) Sensing: as for tracking, it is mission-critical, requires HRT guarantees and a continuous flow of data and thus belongs to the Complete Services model.

C. Smart environments

1) Comfortable homes and offices: this application is interactive or not, it requires no RT or only SRT guarantees but as it can be used for monitoring and alarm systems, it becomes mission-critical. The best classification is thus the Supple Services model.

2) Industrial plants: the application is interactive or not, it requires SRT guarantees, it is mission critical and belongs therefore to the Supple Services model.

3) Smart museum and gym: this is another classic example of Open Services model, it is interactive, does not require RT guarantees and is not mission-critical.

D. Personal and social

1) Social networking: this application is interactive, it doesn't require RT guarantees and isn't mission-critical, therefore it can be categorized into the Open Services model.

TABLE III. APPLICATIONS IN IOT AND THEIR CORRESPONDING SERVICE MODEL

Application domain	Application	Model
Transportation & Logistic	Logistics	Supple
	Assisted driving	Complete
	Mobile ticketing	Supple
	Monitoring environmental parameters	Supple
	Augmented maps	Open
Healthcare	Tracking	Complete
	Identification & Authentication	Supple
	Data Collection	Supple
	Sensing	Complete
Smart Environments	Comfortable homes and offices	Supple
	Industrial plants	Supple
	Smart museum and gym	Open
Personal and Social	Social networking	Open
	Historical queries	Open
	Losses & Thefts	Supple
Futuristic	Robot taxi	Complete
	City information model	Supple
	Enhanced game room	Complete

2) Historical queries: as for social networking, it belongs to the Open Services model for the same reasons.

3) Losses & Thefts: this application is interactive; it requires no RT or only SRT guarantees but is mission-critical, so the best classification is the Supple Services model.

E. Futuristic

1) Robot taxi: enhanced form of assisted driving, it is obvious that this application belongs to the Complete Services model for the same reasons.

2) City information model: this set of applications is interactive or not, it is mission-critical and requires SRT guarantees, therefore it can be categorized into the Supple Services model.

3) Enhanced game room: this application belongs to the Complete Services model as it requires continuous flow of data, HRT guarantees and is mission-critical.

Table III summarizes the above analysis.

VI. CONCLUSION

As a main component of the IoT, WSNs contribute to the management of QoS by optimizing the resource utilization. In this perspective, we first presented a review of current QoS-aware MAC protocols in WSNs, and then we summarized the service models and the performance analysis of the IEEE 802.15.4 from [4]. Afterwards, we presented one of the best ways to integrate WSNs in the IoT providing QoS, using a dense IEEE 802.15.4 access point network, where multiple sensor nodes can join the Internet through the network's gateway. We proposed best practices to adopt when using this protocol in order to provide service models in WSNs. Finally, we demonstrated the feasibility of extension of those service models to the IoT and we categorized different IoT applications according to them.

REFERENCES

[1] O. Vermesan et al., "Internet of Things Strategic Research Roadmap", European Research Cluster on the Internet of Things, Cluster Strategic Research Agenda 2011.

[2] A. Dunkels Adam and J.P. Vasseur, "IP for Smart Objects", Internet Protocol for Smart Objects (IPSO) Alliance, Sepember 2008.

[3] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci. 2002. Wireless sensor networks: a survey. Computer Networks, vol. 38, no. 4, March 2002, pp. 393-422, doi=10.1016/S1389-1286(01)00302-4

[4] M.-A. Nef, S. Karagiorgou, G. Stamoulis, and P. Kikiras, "Supporting Service Differentiation in Wireless Sensor Networks," Proc. 15th Panhellenic Conf. on Informatics, Sept. 2011, pp. 127-133, doi: 10.1109/PCI.2011.49.

[5] W. Heinzelman, J. Kulik, and H. Balakrishnan, "Adaptive Protocols for Information Dissemination in Wireless Sensor Networks, " Proc. 5th ACM/IEEE Mobicom Conf., August 1999, pp. 174-185, doi: 10.1145/313451.313529.

[6] N. Bulusu, D. Estrin, L.Girod, and J. Heidemann, "Scalable Coordination for Wireless Sensor Networks: Self-Configuring Localization Systems, " Proc. 6th International Symposium on Communication Theory and Application (ISCTA 2001), July 2001.

[7] D. Estrin, "Comm'n Sense: Research Challenges in Embedded Networking Sensing, " Presented at the UCLA Computer Science Department Research Review, April 2001.

[8] M. A. Yigitel, O. Durmaz Incel, and C. Ersoy, "QoS-aware MAC protocols for wireless sensor networks: A survey," Comput. Netw., 2011, doi: 10.1016/j.comnet.2011.02.007.

[9] Y.J. Li, C.S. Chen, Y.-Q. Song, and Z. Wang, "Real-time QoS support in wireless sensor networks: a survey, " Proc. 7th IFAC Int Conf on Fieldbuses & Networks in Industrial & Embedded Systems (FeT'07), Nov. 2007.

[10] M. Caccamo, L.Y. Zhang, L. Sha, and G. Buttazzo, "An implicit prioritized access protocol for wireless sensor networks, " Proc. 23rd IEEE RTSS, 2002, pp. 39-48.

[11] T. Watteyne, I. Augé-Blum, and S. Ubéda, "Dual-mode real-time MAC protocol for wireless sensor networks: a validation/simulation approach, " Proc. InterSense, 2006.

[12] S. C. Ergen and P. Varaiya, "PEDAMACS: Power Efficient and Delay Aware Medium Access Protocol for Sensor Networks, " IEEE Transactions on Mobile Computing, vol.5 no.7, pp.920-930, July 2006.

[13] IEEE Std 802.15.4, "Part 15.4: Wireless medium access (MAC) and physical layer (PHY) specifications for low-rate wireless personal area networks (WPANs), " IEEE-SA, 2006.

[14] N. Saxena, A. Roy, and J. Shin, "Dynamic duty cycle and adaptive contention window based QoS-MAC protocol for wireless multimedia sensor networks," Comput. Netw., 2008, doi: 10.1016/j.comnet.2008.05.009.

[15] H. Kim and S.-G. Min, "Priority-based QoS MAC protocol for wireless sensor networks, " Porc 2009 International Symposium on Parallel & Distributed Processing, IEEE Computer Society, 2009, pp. 1-8, doi: 10.1109/IPDPS.2009.5161184.

[16] I. Slama, B. Shrestha, B. Jouaber, and D. Zeghlache, "A hybrid MAC with prioritization for wireless sensor networks, " 33rd IEEE Conference on Local Computer Networks, 2008, pp. 274-281, doi: 10.1109/LCN.2008.4664180.

[17] I. Rhee, A. Warrier, M. Aia, and J. Min, "Z-MAC: a hybrid MAC for wireless sensor Networks, " Proc. ACM Sensys, 2005, pp. 90-101.

[18] M.A. Yigitel, O. Durmaz Incel, and C. Ersoy, "Diff-MAC: a QoS-aware MAC protocol with differentiated services and hybrid prioritization for wireless multimedia sensor

networks," Proc. 6th ACM workshop on QoS and security for wireless and mobile networks, 2010, pp. 62-69, doi: 10.1145/1868630.1868642.

[19] B. Yahya and J. Ben-Othman, "Energy efficient and QoS aware medium access control for wireless sensor networks," Concurrency and Computation: Practice and Experience, 2010, pp. 1252-1266, doi: 10.1002/cpe.1579.

[20] P. Suriyachai, U. Roedig, and A. Scott "Implementation of a MAC protocol for QoS support in wireless sensor networks, " Proc. 2009 IEEE International Conference on Pervasive Computing and Communications, 2009, pp. 1-6, doi: 10.1109/PERCOM.2009.4912839.

[21] K. Fall, K. Varadhan, The ns Manual, The VINT Project, A Collaboration between researchers at UC Berkeley, LBL, USC/ISI, and Xerox PARC, 22 May 2008.

[22] J. Zheng and M. J. Lee, "A comprehensive performance study of IEEE 802.15.4, " Sensor Network Operations, IEEE Press, Wiley Interscience, Chapter 4, 2006, pp. 218-237.

[23] R. Roman and J. Lopez, "Integrating Wireless Sensor Networks and the Internet: a Security Analysis," Internet Research: Electronic Networking Applications and Policy, vol. 19, no. 2, 2009.

[24] D. Christin, A. Reinhardt, P. S. Mogre, and R. Steinmetz, "Wireless Sensor Networks and the Internet of Things: Selected Challenges," Proc. 8th GI/ITG KuVS Fachgespräch Drahtlose Sensornetze, 2009.

[25] L. Atzori, A. Iera, G. Morabito, "The Internet of Things: A survey, " Comput. Netw., 2010, doi: 10.1016/j.comnet.2010.05.01.