Wireless Sensor Networks and LTE-A Network Convergence

Garth V. Crosby, IEEE Senior member
Department of Technology
Southern Illinois University Carbondale
Carbondale, USA
garth.crosby@siu.edu

Farzam Vafa
Electrical & Computer Engineering Department
Southern Illinois University Carbondale
Carbondale, USA
farzam.vafa@siu.edu

***Abstract*— In recent years, machine-to-machine (M2M) networks, which do not require direct human intervention, is increasing at a rapid pace. Meanwhile, the need of a wireless platform with a vast coverage and low network deployment cost for controlling and monitoring these M2M networks has not yet been met. Mobile cellular networks (MCNs) and wireless sensor networks (WSNs) are emerging as two heterogeneous networks that can meet the challenges of M2M communication through network convergence. In this paper, we propose a model for network convergence between a Long Term Evolution-Advance (LTE-A) cellular network and a wireless sensor network. Quality of service (QoS) issues are assessed by a comparative study of the network delay in tight coupling and loose coupling LTE-A configurations. Simulation results indicate that the network delay in our proposed converged network is acceptable for various M2M applications.**

***Keywords*-network convergenge, LTE-A, wireless sensor networks, M2M network, machine-to-machine networks.**

I. INTRODUCTION

We envision a future where millions of small sensors, actuators and other devices form self-organizing wireless networks. This vision relies heavily on the emerging *Internet of Things* paradigm where millions of embedded systems (machines) are able to communicate with and control each other, without human intervention. These machines should seamlessly merge into our daily lives resulting in an enhancement of our well-being. Various aspects of our lives will be affected; some of these include:

- Healthcare: wireless body area networks will collect health data, for example vital signs readings, and transmit this to healthcare provider. Healthcare provider computers will automatically process the data and request ambulance to be sent to patient's address.
- Emergency response: wireless sensor networks will collect data about the status of buildings, bridges and highways. Emergency personnel will be notified if the data collected implies collapsing bridge, collision on highway etc.
- Supply Chain and inventory management: raw material can be tracked from source to retail store in an automated manner. Sensors can determine when raw material is low and communicate to other machines to initiate the supply of more raw materials. This could also take place with little to no human intervention.

Currently, there is no universal platform that facilitates smooth communication for M2M communication via the internet. We attempt to address this lack through proposing a model for network convergence. Our model provides a wireless platform for the convergence of wireless sensor networks and LTE-A cellular networks. We believe that this can provide a cost effective and pragmatic solution for M2M communication. Our main contribution is to propose a novel dual gateway interface for sensor networks and Long Term Evolution advanced (LTE-A) network.

II. RELATED WORK

4G technology is meant to provide what is known as "ultra-broadband" access for mobile devices. LTE advanced, was submitted as a candidate for the 4G system to ITU-T (ITU Telecommunication Standardization Sector) in 2009. It was approved into IMT Advanced and was finalized by the 3rd Generation Partnership Project (3GPP) as a major enhancement of the Long Term Evolution (LTE) standard in March 2011[1].

In [2] an overview of the current state of standardization efforts in M2M communication is given. Lien *et al.* [3] provide an overview of the network architecture and features of M2M communications in 3GPP, and identify potential issues including physical layer transmissions, the random access procedure, and radio resources allocation. They also propose a solution to provide QoS guarantees to facilitate M2M applications with hard timing constraints. In [4] a Mobility architecture, IoMANETS, is proposed for Wireless M2M networks. The design provides a fault tolerant solution to the mobility issue by allowing mobile nodes to seamlessly connect to M2M-Internet of Things infrastructure. The assumptions are that fixed nodes are connected to the internet with either IPv4 or IPv6 and the mobile nodes have IEEE 802.15.4 adapters operating a 6LowPAN IP stack. IoMANETs facilitates the reachability of the device using indirections based on the original global address. Our approach was not focused on fault tolerant connectivity of mobile nodes but was rather on QoS issues in connecting WSN to 4G devices.

Probably the work that is most similar to ours was proposed by Zhang *et al.* [5]. In their work they examined network convergence between mobile cellular networks and wireless sensor networks. They proposed that the mobile terminals in MCN act as both sensor nodes and gateways for WSN in the converged networks. On the other hand, we proposed a separate device that will serve as a dual mode gateway and protocol converter (adapter). In addition, we specifically address LTE-A while the authors in [5] do not specify the cellular technology involved in their proposed converged network.

In [6], the authors proposed node and network models for achieving internet protocol (IP) based direct communication in M2M networks. Their proposal makes several assumptions and cannot be implemented in its current form. Our proposed protocol makes use of the current state of WSN technology and LTE-A to implement, what we believe is, a feasible end-to-end connection between wireless sensor node and a LTE-A device.

III. LTE NETWORK ARCHITECTURE

One of the major goals in 4G systems is to provide a convergence between all IP based networks. The appropriate platform for this purpose should integrate network management, security and QoS. LTE-A satisfies most of the requirements for being a primary platform as a converged networks enabler. It is backward compatible with previous version of 3GPP standards, non 3GPP networks and most of the important IP-based networks such as the Internet. Considering the technical features of the LTE network, which we elaborate on later in this section, and the potential capabilities of network convergence that LTE-A possesses, it is our belief that LTE-A will play a major role in the future of M2M communication. Although other 4G technologies such as 802.16m may be an alternative, the vast majority of subscribers use LTE for wireless communication, thus making LTE a popular choice since their would be comparatively little cost for additional deployment.

The LTE system architecture is all IP-based and therefore is designed to support packet-based transmission. A simplified illustration of the LTE system architecture is shown in Fig. 1.

The two main blocks of the LTE system architecture are the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC). The E-UTRAN is responsible for managing radio access and provides User Plane (U-Plane) and Control Plane (C-Plane) support to the User Equipment (UE). The U-Plane handles a group of protocols used to support end user data transmission through the network; while the control plane contains a group of protocols for managing the connection between the UE and the networks and for controlling the user data transmissions. Some of the connection-management functions include handover, service establishment, resource control, etc. The E-UTRAN consists of only the eNodeBs (evolved Node Base station) or eNBs, where eNB is the LTE terminology for a base station. The EPC is a mobile core network and its main responsibilities include policy management, security and mobility management. The EPC consists of the Mobility Management Entity (MME), the Serving Gateway (S-GW), and the Packet Data Network Gateway (P-GW).

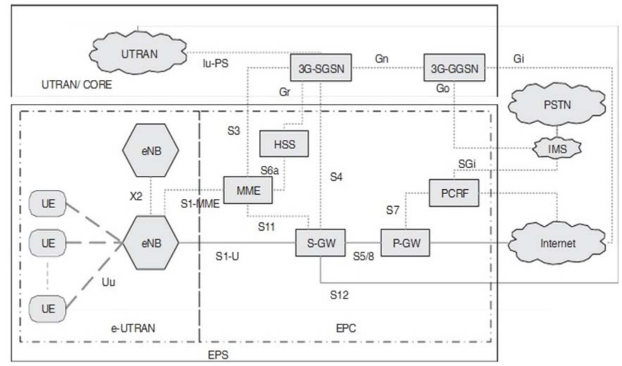

Figure 1. LTE Simplified LTE system architecture. Taken from [7]

IV. M2M NETWORKS

M2M is the concept of enabling the flow of data between machines. The major goal of the M2M network is to bridge the collected data by the machine with the existing communication network. Regardless of the type of device or data, information usually flows in the same general way; gathered from a machine over a network, and then goes through a gateway to a controlling system where it can be processed and acted upon.

M2M communication is mostly used in four platforms: smart grids, home networking, health care and vehicular networks. The Smart grid is an integration of a power network and an information network designed to improve the efficiency of power transmission, enhance the quality of service, and to reduce the economic and environmental cost [8]. The major purpose of home networking is media distribution. However, it can also include elements of the smart grid network as described earlier. Media distribution systems consist of media storage (media server), media transportation (Wi-Fi, Bluetooth) and media consumption (laptops, smart phones, tablets) [9]. Health care M2M networks are used to monitor peoples' health and inform monitored patients, as well as their doctors, of any abnormal conditions that may occur. Sometimes, in order to measure the health parameters, such as blood pressure, cholesterol blood sugar level and so on, miniature sensors are implanted inside human's body to form a wireless body area network (BAN). Body sensors are all connected to an on-person gateway, such as a cell phone, which also acts as the collectors for all data sensors. Sensors send the data to the cell phone, which in-turn sends the data over the cellular network to health monitoring servers. Several research efforts have been done on M2M communications support for vehicular networks in recent years. Inside a car, M2M network is utilized as a controlling part of the vehicle known as controller area network (CAN). In a vehicular network, M2M communications is divided into four different categories: traffic management, vehicle telematics, safety & collision avoidance, and entertainment [10].

There are two main restrictions in M2M communications: power consumption and computational capability. In most of the M2M networks, machine type nodes do not have access to permanent source of energy. The most common power supply for machine type node is battery. Therefore, long distance wireless communication is not feasible in M2M communication since the high power transmission cannot be supplied with a miniature battery. Also, depending on the application the computer capability of the sensor nodes may be extremely limited. For example, an implantable body sensor node has very limited memory and computing capability.

V. M2M AND LTE-A NETWORK CONVERGENCE

M2M communication is one of the focuses of the LTE-A project, as the demand for M2M is increasing rapidly. Within the next several years M2M communications are expected to eventually exceed the number of H2H (human-to-human) communications. A primary driver for the replacement of H2H by M2M communication is that there are almost 50 billion machines in the world, but only 6 billion people.

A. Our Dual Gatweawy Model

In this paper, a tight coupling dual mode gateway is proposed. Employing a dual mode gateway for merging two networks enables us to use the specific features and protocols for each network individually. Our WSN network employs the IEEE 802.15.4 standard and 6LoWPAN protocol stack, which enable us to address all the nodes individually using the IPv6 protocol. This also facilitates power efficient connections among the resource-constrained nodes in the WSN. The WSN network is connected to the LTE-A network via our dual mode gateway so that all nodes can be controlled and monitored by the LTE system through the gateway. Our model is similar in configuration to the architecture proposed by Liu *et al.* [14] shown in Fig. 2.

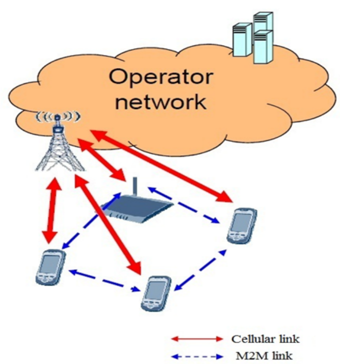

Figure 2. Dual mode gateway model. Taken from [14]

B. Merging Network Techniques

There are two major techniques for networks integration: loose coupling and tight coupling. In the loose coupling method of inter-networking, networks are interconnected to each other indirectly. For instance, the first network is connected to the IP network to obtain an indirect link with the second network. Fig. 3 depicts the topology of the loose coupling method. In the tight coupling inter-networking method, the first network is connected directly to the second network. In such an internetworking scenario, the first network's gateway is connected directly to the access layer of the second network. Specifically, in the LTE-A WSN model the WSN gateway can be merged to the UE (User Equipment) resulting in the creation of a dual mode radio. This method is quite efficient in term of end-to-end latency. However, to the best of our knowledge, prior to our work no dual mode gateway has been design for LTE-A WSN convergence. Hence, we proposed our dual mode gateway using tight coupling to connect LTE-A cellular and WSNs. The topology of our tight coupling dual mode gateway is shown in Fig. 4.

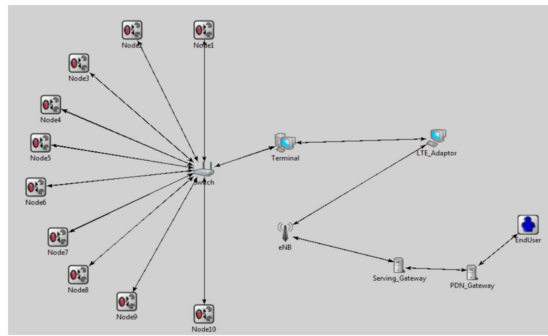

Figure 3. Loose coupling topology

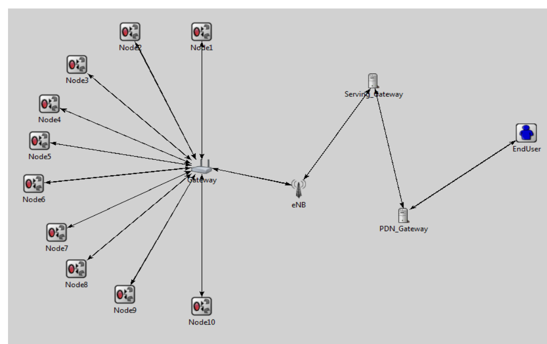

Figure 4. Tight coupling method with dual mode gateway

C. Protocol Conversion

The protocol stacks of 6LoWPAN and the User Equipment (UE), which is the last node in the access layer of E-UTRAN are not the same. Therefore, protocol conversion should occur in the gateway to make the receiving packets compatible with the LTE-A network and vice versa. The protocol stacks of 6LoWPAN and UE are shown in Fig. 5.

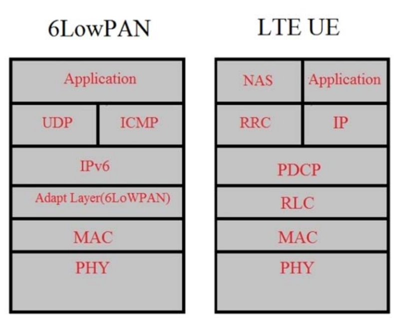

Figure 5. 6LoWPAN and LTE UE protocol stack.

Since the connection is IP based, there is no need to reach the layers above the IP layer. The MAC layer of LTE UE consists of MAC header and RLC payload. The MAC header size is 42 bytes and the RLC payload is 400 bytes. The maximum size of the input packet coming from the WSN is 147 bytes. It is obvious that the packet coming from the WSN network fits in the LTE MAC layer payload. As can be seen in Fig. 1, in the User plane of the LTE network, the received packet from UE is passed to the eNb. LTE network's compatibility enables us to transfer the incoming packet from the WSN network to any other IP-based network. Evolved UTRAN (EUTRAN) enables us to exchange data through the SGW (Serving Gateway) and PGW (PDN Gateway) between the dual mode gateway and the IP-based network.

VI. RESULTS AND DISCUSSION

We used OMNET++ to conduct our simulation studies. Our main issues were: (i) making reliable connections and (ii) evaluating the end-to-end delay in our converged network. We did a comparative study of both loose and tight coupling. Our network setups for loose coupling and tight coupling are in shown in Fig. 3 and Fig. 4, respectively.

In our simulation we utilized a single gateway that separates the two heterogeneous networks, that is, the WSN and the LTE-A cellular network. For simplicity, we deployed 10 nodes in our WSN. We did this since we were mainly concerned with end-to-end connections. The reliability of the converged network was limited by the low power, lossy channel of the WSN. Utilizing IEEE 802.5.4 and 6LoWPAN are among the best options for this type of network (Low Power Lossy Network) and were therefore utilized in our simulations. We were also cognizant of potential bottlenecks at the dual mode gateway. This however, was an issue of scalability and could easily be addressed by providing multiple gateways. Nonetheless, issues of scalability were not the focus of our research and hence were not addressed in our simulation studies. The delay at the gateway as a result of buffering and protocol conversion processing was negligible with respect to the delay caused by the noisy channel of the WSN. Thus, this was ignored.

Fig. 6 depicts the end-to-end transmission delay time in loose coupling and tight coupling. The graphs imply that by using the proposed tight coupling method the end-to-end delay time can be decreased significantly from 900 milliseconds at the maximum to 500 milliseconds, which would be a significant enhancement for real time networks or systems with low latency restrictions. Also, this would meet the requirements for various applications of real-time M2M networks.

VII. CONCLUSION

In this paper, we proposed a model for WSN and LTE-A network convergence. Our results indicate that this is a viable option that meets the delay requirements of various types of M2M applications. This research work is ongoing and we will address issues of power efficiency and consumption of the proposed model. We also intend to conduct test-bed experimentations of our model. Finally, a more comprehensive QoS assessment is suggested for future work.

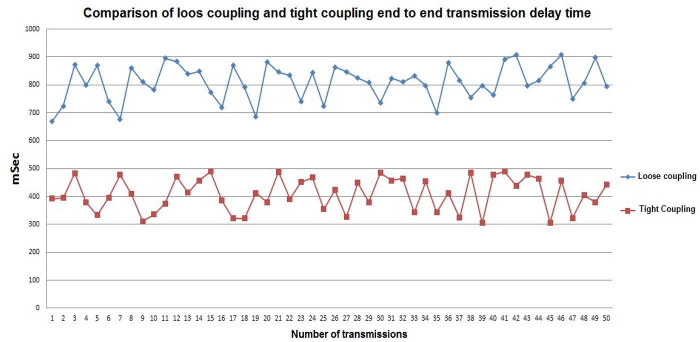

Figure 6. Comparison of loose coupling and tight coupling methods end-to-end transmission delay time.

REFERENCES

[1] "ITU's History," International Telecommunication Union, 2011.

[2] D. Lee, J. Chung, and R. Garcia, "Machine to Machine Communication Standardization Trends and End to End Service Enhancements through Vertical Handover Technology," in the proceedings of IEEE 55th International Midwest Symposium on Circuits and Systems (MWSCAS), 2012, pp. 840-844

[3] S. Lien and K. Chen, "Toward Ubiquitous Massive Accesses in 3GPP Machine-to-Machine Communications," IEEE Communications Magazine, April 2011, pp. 66-74

[4] A. Attwood, M. Merabti and O. Abuelmaatti, " IoMANETS:Mobility Architecture for Wireless M2M Networks," in the proceedings of IEEE GlobeCom Workshop, the International Workshop on Machine-to-Machine Communications, 2011, pp. 399-404

[5] J. Zhang, L. Shan, H. Hu, and Y. Yang, " Mobile Cellular Networks and Wireless Sensor Networks: Towards Convergence", IEEE Communications Magazine, vol. 50, no. 3, March 2012, pp. 164-169

[6] Y. Igarashi, M. Ueno, T. Fujisaki, " Proposed Node and Network Models for an M2M Internet", in the proceedings of the World Telecommunications Congress (WTC), pp. 1-6, 2012

[7] L. Korowajczuk, "LTE, WiMAX and WLAN Network Design, Optimization and Performance Analysis", Chennai, India: Wiley, Aug. 2011.

[8] M. Booysen, J. Gilmore, S. Zeadally and G. Rooyen, "Machine to machine communication in vehicular networks," [Online] http://hdl.handle.net/10019.1/20768, Accessed: August 2012

[9] W. Mohr, "Mobile Communication Beyond 3G in the Global Context," Siemens mobile, 2007. [Online] http://www.6ip.cu/pdf/werner_mohr.pdf, Accessed: October 2012

[10] D. Culler and J. Hui, "6LoWPAN Tutorial-IP on IEEE 802.15.4 Low-Power Wireless Networks", [Online] http://www.cs.berkeley.edu/~jwhui/6lowpan/6LoWPAN-tutorial.pdf, Accessed: September 2012

[11] Network Computing Magazine. [Online]. http://www.networkcomputing.com/ipv6/six-benefits-of-ipv6/230500009

[12] C. Blackman, "Convergence between telecommunications and other media: how should regulation adapt?" in Telecommunication Policy, Elsevier, vol. 22, no. 3, April 1998, pp. 163-170.

[13] W. Wang and Y. Chen, "Machine-to-Machine communication in LTE-A," Research & Innovation Center Alcatel-Lucent Shanghai Bell , 2010.

[14] Y. Liu, B. Zhen, Y. Xu, H. Yang and B. Zhao, " Current and Future Trends in Hybrid Cellular and Sensor Networks" , ETSI TC M2M Workshop, Huawei Technologies Co. Ltd., October 2010, Sophia Antipolis, France.