Smart Grid Traffic Modeling and Scheduling Using 3GPP LTE for Efficient Communication with Reduced RAN Delays

Muhammad Basit Shahab, Asif Hussain, and Muhammad Shoaib

***Abstract*—There has been a dramatic improvisation in communication technologies during the last two decades. This in turn has evolved as a great source of strength to ideas regarding implementation of smart grids. This paper has three basic emphasis areas. At first, it presents a smart grid top to down hierarchy tree based traffic model by considering the different types of information carrying traffic travelling between multiple nodes of a smart grid. This is done by analyzing the multiple functions performed by a smart grid. After that 3GPP LTE is addressed as the most promising communication backbone for smart grid environment. Its performance has been analyzed in terms of high data rates, improved coverage and reduced Scheduling and Transmission delays. In the end, a priority based queuing technique for smart grid traffic is proposed by categorizing the smart grid traffic into different classes with each class representing a different type of information/data. This results in reducing the queuing delays of traffic at end and intermediate nodes. It has been shown through results that the proposed traffic modeling, scheduling and queuing result in reduced Random Access Network (RAN) delays.**

***Keywords*—Smart Grid, 3GPP Long Term Evolution (LTE), Traffic, Micro grids, Scheduling, RAN Delays, Queuing**

I. INTRODUCTION

SMART grid is simply an electric grid that utilizes communication and information technologies to receive and gather information like consumers and suppliers behavior, and respond to it accordingly. This is done in an adaptive fashion to improvise the reliability, flexibility in network topology, efficiency, load adjustment, peak curtailment/leveling and time of use pricing, demand response support, platform for advanced services, power flow control, economics, and sustainability of the distribution and protection of electricity. Different operations/functions of a smart grid are depicted in Fig. 1.

Manuscript received February 11, 2013. This work has been sponsored by the Higher Education Commission of Pakistan.

M. B. Shahab is Lecturer at Electrical Engineering Department, University of Management and Technology, Lahore, Pakistan. (Phone: +92-333-9299532; Email: basit.shahab@umt.edu.pk)

A. Hussain is Assistant Professor at Electrical Engineering Department, University of Management and Technology, Lahore, Pakistan. (Phone: +92-333-4592047; Email: asif.hussain@umt.edu.pk)

M. Shoaib is Lecturer at Electrical Engineering Department, University of Management and Technology, Lahore, Pakistan. (Phone: +92-333-8166272; Email: muhammad.shoaib@umt.edu.pk)

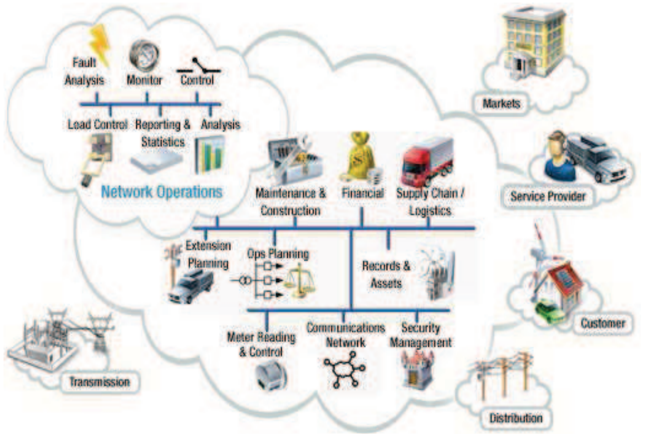

Fig. 1 Operations of a Smart Grid

The basic elements/systems of smart grid are:

- Asset Management Systems (AMS) and Condition Monitoring Devices (CMD)
- Decision Support Systems (DSS) and System Integrity Protection (SIP)
- Distribution Automation and Protection (DAP)
- Energy Management System (EMS)
- Information and Communication Technology (ICT) and Local Production (LP)
- Power Quality and Power Monitoring Systems (PQPMS)

Smart grid network is a hierarchy tree with users acting as the end nodes or leaves of the tree and main grid or a server at the top of tree thus enabling a two way movement of information between individual customers and power plants [1] [2]. Through shared information on requirements and capabilities among power providers, distributors and consumers , electricity usages can be dynamically and intelligently adjusted, so that the grid network is more efficient and reliable [3], [4]. As far as the communication architecture is concerned, the Smart Grid consists of following four basic layers:

- Physical power layer (PPL) including generation, transmission, distribution and consumption.
- Data Link Layer (DLL) comprising data transport and control. It enables two-way information flow in each part of the PPL.

- Network Layer (NL) for routing the information according to the required destinations.
- Applications layer (AL) which deals with services.

Considering the recent advancements in communication techniques, there is a great choice of selection of any one of them to be used in smart grids. Some of them that got famous to be used in smart grids are Power Line Communication (PLC), IEEE 802.15.4 (ZigBee), IEEE 802.11 (Wireless LAN (WLAN) or Wi-Fi), IEEE 802.16 (WiMAX), GSM, GPRS, Optical Fiber and LTE/ LTE-A.

All these techniques can be used to perform the required flow of information but the selection of any one to communicate this data depends on some key factors. The most important of these factors is high data rate or less delay. Out of these techniques LTE seems to be the most promising techniques because it aims at high data rates [5] [6] , low delay/latency, high spectral efficiency, high performance broadcast services, cost effective network design, coverage and capacity optimization, energy saving and interference reduction.

The major issue after selecting a particular technique for communication is to design a model and a corresponding technique to carry the information according to the priority of data. Therefore, this paper categorizes the smart grid data/traffic into four classes according to their priorities in terms of delays and also because of their importance in terms of services to be provided according to them. These four categories are:

- Class A: Faults and other emergency situations (Alarm Data)
- Class B: Smart metering data (SMD) and control
- Class C: Remote real time monitoring and event notification
- Class D: VoIP traffic

After categorizing the traffic into different classes, the paper proposes a mechanism using low cost protocols by providing different priority at the data link layer of smart grid communication infrastructure. The proposed technique makes sure that high priority information is processed relatively faster as compared to the traffic with low preference.

II. SMART GRID HIERARCHAL TRAFFIC MODEL

The smart grid hierarchal infrastructure follows the shape of a tree. The bottom end nodes or the leaves of the structure are users/consumers. The smart metering data from the consumers reaches the local grids (grids within a city) enabling them to calculate or monitor the load at each local grid. This data consists of the real powers utilized by different consumers helping the local grids to calculate the real time load served by them at different times. There are some micro-grids present in the network injecting power to the users or injecting it back to the local grids.

Suppose there are n_i micro-grids and each micro-grid serves m_w users with power factors θ_{iw}, therefore, the total power delivered by the micro-grids is the sum of power

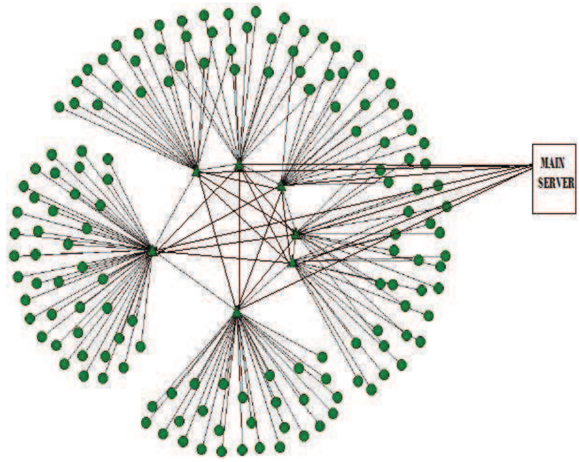

Fig. 2: Hierarchal Communication Architecture

delivered by each micro-grid. This can be calculated by a formula similar to equation (1)

$$P_m = \sum_{i=1}^{n_i}\sum_{w=1}^{m_w} P_{iw} = \sum_{i=1}^{n_i}\sum_{w=1}^{m_w} V_{iw} I_{iw} \cos(\theta_{iw}) \qquad (1)$$

These micro-grids add to the total load present in the network. The basic thing of interest is the load supplied by local grids. Suppose there are n_j local grids and each local grid serves m_x users, then the total power delivered by local grids is calculated in the same way in equation (2)

$$P_l = \sum_{j=1}^{n_j}\sum_{x=1}^{m_x} P_{jx} = \sum_{j=1}^{n_j}\sum_{x=1}^{m_x} V_{jx} I_{jx} \cos(\theta_{jx}) \qquad (2)$$

The total power consumed by the load is the sum of *Pm* and *Pl* as shown in equation (3)

$$\begin{aligned} P_T &= P_m + P_l \\ &= \sum_{i=1}^{n_i}\sum_{w=1}^{m_w} V_{iw} I_{iw} \cos(\theta_{iw}) + \sum_{j=1}^{n_j}\sum_{x=1}^{m_x} V_{jx} I_{jx} \cos(\theta_{jx}) \end{aligned} \qquad (3)$$

The power consumption feedback is provided by the smart metering part of smart grids. This load monitoring is executed at the local grids and the micro-grids. This is the class B traffic. After that signals, representing different types of faults and emergency conditions occurring at local grids or on the lower level/micro-grids (Class A traffic), remote real time monitoring Class C traffic representing cameras and other notifications, and the class D VoIP traffic are communicated between different grids through a Mesh Junction Network (MJN). This complete set of data is also communicated one step up in the hierarchy tree. In the same way the information is forwarded to the main serving node. This hierarchal architecture is shown in Fig. 2.

III. TRAFFIC SCHEDULING USING LTE

The smart grid communication needs to be done through some proper way of communication technique which has a

TABLE 1
NIST SMART GRID REQUIREMENTS DETAILS

Application	Smart Metering		Distribution Automation	
Downlink/ Uplink	Uplink	Downlink	Uplink	Downlink
	[min,max]	[min,max]	[min,max]	[min,max]
How often (Event/Device /Second)	4.88E-04	1.51E-05	0.0515[0,0.4]	0.0514 [0,0.4]
Average Payload (Bytes/Event)	2264 [25,2400]	25.8K [25,2000K]	148.47 [25,1000]	100.34 [25,500]
Data Rate (Bit/Second)	8.84	3.12	761.88	585.3

much more improved capacity, coverage and high data rates to convey the information in a manner that reduces the latency/delay of the data to reach the main node or the required destination. The most promising one, especially out of all the wireless communication techniques is the 3GPP Long Term Evolution Release 8. The process of controlling different things by the high level nodes on the basis of information sent from the lower level nodes is called Distributed Automation (DA). After smart metering, DA has become a second wave of smart grids. Government of Canada has allocated frequency spectrum of 30 MHz in 1.8 GHz for smart grid applications, whereas WiMAX based solutions for smart grids have been presented by some companies in Australia [7]. Smart grid main applications are Smart Metering (SM), Distributed Automation (DA), Demand Response (DR) and Wide Area Monitor (WAM).

For last-mile applications like SM and DA, cellular technology is much more suitable [8]. The feasibility of using any of the communication techniques for Smart Grids and especially in DA are based on the requirements documents released by Nation Institute of Standards and Technologies (NIST) shown in Table 1 [9]. The requirement of small delay and better coverage makes LTE an excellent way of SM communication. One important reason behind this is that LTE has a great advantage that it can schedule or assign resources to the user traffic in both Time Domain Duplex (TDD) and Frequency Domain Duplex (FDD) modes. Other wireless techniques even the 3GPP Release 6 and 7 (HSPA and HSPA+) assign resources in only time domain. This is the basic reason why LTE has data rates or throughput 3-4 times HSPA in downlink and 2-3 times in uplink.

Now when it comes to applying LTE for SM communication, the first important thing to be kept in mind is that the SM traffic is actually hybrid comprising of Periodic data and Random Data coexisting with each other. This is because some traffic types flow in a periodic order like metering information, whereas some traffic are at random like faults notification. For 50 feeder sensors, the total periodic traffic load is 12 Kbps in downlink and 24 Kbps in uplink respectively. Therefore any dynamic Scheduling technique in LTE can be used to carry this traffic. The most severe or worst case Random Access Network (RAN) delay is 100 ms. It is actually the sum of Queuing delay (QD), Scheduling delay (SD) and Transmission Delay (TD) as shown in equation (4) [9].

$$RAN\ Delay = \sum_{i=1}^{n} (QDi + SDi + TDi) \qquad (4)$$

Where i is the data of a particular class of traffic, while *TDi*, *SDi* and *QDi* are the transmission, scheduling and queuing delays for the ith class of traffic

Now these delays always play their part both in downlink and uplink Smart Grid traffic delays. Therefore LTE should be used in such a way so as to reduce these delays both in downlink and uplink. The queuing delays among them can be mitigated by using some reserved bandwidth for the high priority Random traffic data because of their low arrival rates. Although the normal Scheduling time/delays in LTE Release 8 are 10 ms, which means that LTE reassigns or reschedules data packets after some milliseconds, yet this delay needs much more point of thought in the DA because a lot of devices reach an idle state due to low traffic densities. Before traffic transmission to or from these devices they need first to be shifted from idle mode to an active or connected mode, and then the data needs to be sent to it. In this scenario for the Time Domain Duplex frame structure, the average transition/scheduling time is 86.6 ms with the setting of 5.5-6.5 ms window and 5 ms Physical Random Access Channel Cycle [10], therefore leaving only 13.4 ms available for the data, making the reliability requirements satisfaction of 99.5 % impossible with only 1 HARQ (Hybrid Automatic Repeat Request). The problem can be resolved by keeping all field devices on line. Transmission delays are the amount of time required to move the traffic from one end to the other end on either downlink or uplink, which is always very less in LTE based systems because of their high data rates.

From the discussion above, it can be easily said that the transmission delays are only a function of distance because the data rate is known for end to end communication between the two end nodes. Scheduling delays can be reduced by keeping all field devices on line, so that the delays due to transition from idle to connected are not present. But in order to keep minimum delays for the high priority class traffics, bandwidth is reserved for them, resulting in very low queuing delays at the cost of some fall in the spectral efficiency. The bandwidth or the packets provided by LTE to each data packet is in the form of Resource Blocks (RB). Each LTE Frame consists of 10 ms divided into 10 sub-frames of 1ms each, where each sub-frame is divided further into two slots each of 0.5ms. This 0.5 ms slot is known as RB. This has been depicted in Fig. 3.

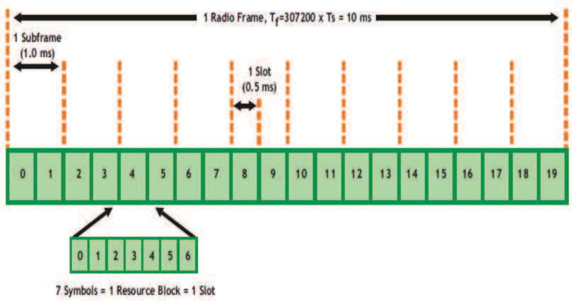

Fig. 3 Division of LTE frame into RBs

These RBs are actually resources to carry data. For high data traffics or the high data traffics users, more RBs should be allocated so that they can provide more capacity in terms of bits/sec to these particular traffics.

Now to avoid queuing delays for the high priority random traffics, 4 RBs are allocated to them, so that an 80-byte packet can be transmitted in one Transmission Time Interval (TTI). One transmission time interval means the scheduling time, which for LTE is 10ms. This means that after each frame is passed, the resources or the RBs are reallocated according to the traffic travelling at that moment. The rest of the resource blocks in each frame are left to be assigned to the other traffic types. To give a conclusive idea about this traffic modeling, a traffic model and queuing technique has been proposed in the next section to priorities the traffic according to their priorities, so that the high priority traffic gets very less queuing delays.

IV. QUEUING MODEL

The proposed traffic model categorizes the smart grid traffic into four different classes on the basis of their priority corresponding to the data they carry on the uplink and the actions/control that need to be performed when communicated on the basis of this data through downlink. These four classes are

- Class A: Faults and other emergency situations (Alarm Data)
- Class B: Smart metering data (SMD) and control
- Class C: Remote real time monitoring and event notification
- Class D: VoIP traffic

The technique considers Class A traffic as high priority because of the type of data it carries. So it is desired that it has the minimum queuing delay. 2nd, 3rd and 4th priorities are of Class B, C and D respectively. The packet of each type of traffic is identified with the help of unique small identifiers such as DSCP (differentiated service code point) in the headers. At the edges of the network, traffic identification or classification is performed. At all the intermediate nodes, particular forwarding techniques which are called Per-Hop-Behavior (PHB) are performed on the incoming packets. It provides suitable delay-bound, jitter-bound and bandwidths for each traffic class packets. A service differentiation unit is used to support differentiated services. At the top most nodes of the smart grid communication tree, all this Smart Metering and other traffic is analyzed and then the DA part has to play its role, which means generating different control signals to be communicated down the hierarchal tree. By using 3GPP LTE in the uplink and the downlink, data rates have been improved. Also the Scheduling and Transmission delays are decreased. The third portion of the overall RAN delays as mentioned in equation (4) is the queuing delay. This delay is reduced using this traffic model to analyze the data and respond to it in time.

Now as the SG traffic is classified into different types, for the first high priority traffic class, non-primitive queuing is applied. On the other three types of traffics a weighted queuing method is used such as weighted Round Robin technique which tries to treat all these traffic in an equal manner with slight differences dealt by these weights. The mean arrival time for each type of traffic data is calculated by using equation (5)

$$\theta i = \frac{Li}{Bi} \tag{5}$$

Where Bi is the bandwidth for each type of traffic and Li represents the packet size of each traffic type. Another important parameter is the Mean Service Time, which is calculated as in equation (6)

$$\gamma i = \frac{C}{Li} \tag{6}$$

C represents the output bandwidth calculated using (7)

$$C = \alpha \sum_{i=1}^{k} Bi \tag{7}$$

Where α is a constant factor between 0 and 1. In this specific type of queuing, input packets of priority class i, i=1, 2… k, arrive at the system according to a Poisson Process with the rate θi. Both service and arrival times are considered as independent. If the traffic intensity of each traffic class type is represented by ϵi, then our main objective is to compute the system time Ti of class i input packets and the waiting time Wi in the queue. Implementing queuing theory, waiting time and System Time for each type of traffic data are computed using equation (8) and equation (9)

$$w_i = \frac{\sum_{j=1}^{m} \theta_i h_j^{(2)}}{2\left(1-\sum_{j=1}^{i-1}\rho_j\right)\left(1-\sum_{j=1}^{i}\rho_j\right)} \tag{8}$$

$$T_i = \frac{1}{\gamma_i} + \frac{\sum_{j=1}^{m} \theta_i h_j^{(2)}}{2\left(1-\sum_{j=1}^{i-1}\rho_j\right)\left(1-\sum_{j=1}^{i}\rho_j\right)} \tag{9}$$

Where $h_j^{(2)}$ is the second moment of service time class j.
The dynamic Bandwidth allocations for traffics with different Quality of Service requirements are shown in Table 2.

The final simulation results for waiting times for each type of traffic in the queues are demonstrated in Table 3.

TABLE 2
DYNAMIC BANDWIDTH ALLOCATION FOR DIFFERENT QOS

Traffic Class	Latency (ms)	Bandwidth (kb/s)	Examples (Application)
Class A	8-10	64	Teleportation
Class B	200	512	SCADA
Class C	100	1.2-64	WACS
Class D	200	8-64	VoIP

TABLE 3
SIMULATION RESULTS FOR WAITING TIME

Traffic Class	θ_i	Analytical w_i	Simulated w_i
Class A	0.002	0	0
Class B	0.003	2.59 E-06	2.60 E-06
Class C	0.004	5.28 E-06	5.37 E-06
Class D	0.004	7.24 E-05	7.41 E-05

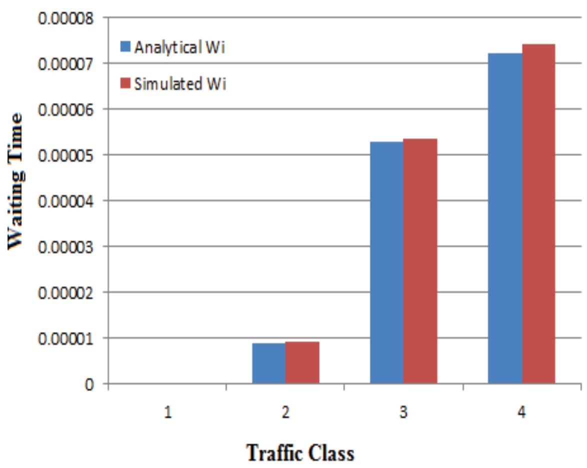

Fig. 4 Traffic Class vs Waiting Time Comparison for Simulated and Analytical Results

Comparisons of Analytical waiting times and simulated waiting times are shown in Table 3 and are demonstrated in Figure 4.

This graph clearly demonstrates that the analytical waiting times for a particular type of traffics required by smart grid efficient operations are comparable to the results deduced from the waiting times of the proposed technique. The high priority class A has 0 waiting time as its information doesn't need to be delayed for proper operations.

V. CONCLUSIONS

This paper deals with three major aspects of small grid. At first it presents a top to down hierarchal architecture of smart grid demonstrating the way in which two- dimensional information can flow. It makes a very clear picture of how the conventional grids and the micro grids can be integrated to fulfill the electricity requirements of the users and how the smart metering information along with other important data is communicated up the hierarchy to the Master grid or the Server to perform different control actions accordingly. It also shows how the conventional grids and micro grids can communicate with each other too.

In the second portion, the paper has addressed the appropriate wireless technique to fulfill the required data rates and delay/latency requirements. It is clearly shown that 3GPP LTE is one of the most promising technique that can be used for smart grid data communication because of its high standards, data rates, spectral efficiency and minimum delay/latency. The basic frame structure of LTE in the TDD and FDD modes is also discussed, which enables one to understand how the data will be communicated using resource scheduling in 3GPP Long Term Evolution. It is also discussed how the two basic parts of RAN delay i-e scheduling delay and transmission delays can be reduced using LTE.

In the final part, a queuing based hybrid traffic model is discussed. This traffic model uses some identifiers to differentiate different traffic and then analyze them and work accordingly. It uses queuing theory and some priority based weighted technique to make sure that each type of traffic gets the same possible delays that are close to those acceptable in reality. Also the highest priority traffic has been made to have 0 queuing delay. In this way the third type of RAN delay called the queuing delay is also controlled, thereby improving the performance of smart grid communication in terms of data rates and delay/latency. The queuing delay results have also been shown through graphs.

REFERENCES

[1] Jahangir Mohammed, "Realize the promise of M2M- make it work out of the box," Ericsson Business Review, Nov, 2010.

[2] G. Wu. S. Talwar, K. Johnsson, N. Himayat, and K. D. Johnson, "M2M: from mobile to embedded Internet," IEEE Communication Magzine, vol. 49. No.4, pp:36-43, 2011.

[3] Z. Fadlullah, M. Fouda, N. Kato, A. Takeuchi, N. Iwasaki, and Y. Nozaki, "Toward Intelligent Machine-to-Machine communications in Smart Grid," IEEE Communication Magzine, vol. 49, No.4, pp:60-65.

[4] H. Sun, H. Wan, J. Wang , Y. Xia, Z. Xu and P. Zhang, "Smart Transmission Grid: Vision and Framework," IEEE Transaction on Smart Grid, vol. 1, No.2, pp:168-177.

[5] E Dahlman, S. Parkvall, J. Sköld, and P. Beming, 2007, "3G Evolution –HSPA and LTE for Mobile Broadband," Elsevier.

[6] 3GPP TR 25.913, 2008. "Technical Specification Group Radio Access Network; Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN)," Release 7.

[7] S. Lancashire and K. Adeleye, "Smart Grid communications," IEEE P2030-10-0056-00-0011, 2011.

[8] G. Wang, X. Zhong, S. Mei and J. Wang, "An adaptive medium access control mechanism for cellular based Machine to Machine (M2M) communication," In Proceedings of IEEE ICWITS 2010, 2010.

[9] 3GPP TS 23.888, "System improvements for Machine-Type-Communications".

[10] 3GPP Technical Report 36.912, "Feasibility study for Further Advancements for E-UTRA (LTE-Advanced) (Release 9)".