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Resource Efficient Advanced Metering Infrastructure Model

Josephina Kimambo, Kwame S Ibwe*, Ellen Kalinga and Abdi T. Abdalla
College of Information and Communication Technologies, University of Dar es Salaam
P. O. Box 33335, Dar es Salaam, Tanzania
**Corresponding author e-mail: kwame.ibwe@gmail.com*
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Abstract

Advanced Metering Infrastructure (AMI) enables two-way communication between smart devices and utility control centers. This involves remote monitoring and control of energy consumption as well as other parameters in the electrical power network in real time. However, increasing technologies in AMI due to huge deployment of smart meters, integration of devices and application of sensors, demand a strong architectural model with the best network topology to guarantee efficient usage of network resources with minimal latency. In this work, a resource efficient multi-hop network architecture is proposed using hybrid media access protocols. The architecture combines queuing and random-access protocol to achieve optimal network performance. Numerical results show that the probability of delay incurred by an arbitrary smart meter depends on the mean and distribution of the queue switch over a period. It is also observed that for a single queued system, the throughput performance is equal to the existing hybrid method. As the number of smart meters increases to 500, the throughput of the proposed method improves by 10% compared to the existing method. Likewise, as the number of smart meters increases to 500, the delay reduced by 15% compared to the existing method.

Keywords: Advanced Metering Infrastructure; hybrid media access protocols, Smart Meter; Smart Grid; Power Network.

Introduction

The use of Information and Communication Technologies (ICT) to manage the electrical power network has resulted in a smart grid (Huh and Seo 2015, Dileep 2020, Kochański et al. 2020). Smart grid is a new generation of power system that has two types of network infrastructures, the power and the communication infrastructure (Talaat et al. 2020, Chakraborty et al. 2021). The entire communication infrastructure consists of three parts: The Home Area Network (HAN), which interconnects households or devices within industry in short-range coverage, the Neighborhood Area Network (NAN), which acts as an interface between HAN and a central utility center; and the Wide Area Network (WAN), which connects two or more NANs from different localities.

Advanced Metering Infrastructure (AMI) is a subsystem of the smart grid, at the consumer side, which automates reading and the billing of power consumption (Le et al. 2016, Gunduz and Das 2020). The AMI needs a two-way communication setup between a group of smart meters and the utility center through a data aggregator or gateway (Maamar and Benahmed 2019, Korba et al. 2020, Kabir et al. 2021). AMI traffic should be delay-tolerant, periodic in most cases, or event-based on a few cases with small burst size (Krishna et al. 2019). The critical factors that affect network performance are number of devices, high overheads and load variations (Krishna et al. 2019).

The IEEE 802.11s is the open standard used in NANs which extends the single-hop functionality of the widely used IEEE 802.11 series (Hiertz et al. 2007). It is adding multi-hop capability, employing a path-selection mechanism at the media access control (MAC) layer, and supporting internetworking through a gateway called the Mesh Portal Point (MPP) (Zhang et al. 2018, Ghasempour 2019, León et al. 2020). In this standard, smart meters form a mesh network with other smart meters in the NAN. These smart meters send consumer power consumption data or other information to the gateway which will relay them to the utility company through a WAN (Rajan and Nambeti 2020). In a mesh topology, bandwidth between devices is improved compared to a ring structure by providing a dedicated link between every device.

The NANs in smart grid are expected to serve a number of applications in addition to smart meter data collection such as outage detection, demand response, electric vehicle charging coordination and security certificate distributions (Ma et al. 2018, Avancini et al. 2019, Rehmani et al. 2019). This means that there will be an increased traffic on NANs as new applications of the smart grid come to life. Note that periodic operations of IEEE 802.11s such as establishing and maintaining peering between smart meters, building the network topology, and maintaining the proactive paths to all smart meters through the gateway already create a significant amount of traffic (Tonyali et al. 2018). The situation is compounded with the upper protocol layer operations. It has been reported that the operation of the network layer protocol such as Address Resolution Protocol (ARP) increases the contentions and eventually causes the network performance degradation (Saputro and Akkaya 2017). Considering all of these at the same time, the AMI network may experience a lot of congestion and interference which may increase data delay as well as the packet loss. Such performance metrics can be critical in meeting certain Quality of Service (QoS) requirements from smart grid applications such as demand response or distribution side state estimation. Therefore, there is a need to improve the traffic congestion (Diovu 2018).

The authors in Matsuzawa and Takahashi (2016) proposed a hybrid communication architecture to accommodate different types of communications in the same network. Their architecture sequentially combines a polling protocol for regular data collection and a random access protocol for infrequent or occasional data communication. However, the paper is silent on how the acknowledgement overhead is dealt with to minimize delay.

In Japan, Tokyo Electric Power Company adopted multihop wireless communication as a Field Area Network for AMI, in which each meter transmits its own packets and relays those transmitted by other meters to gateways like a bucket brigade in multihop wireless networks (Matsuzawa and Takahashi 2016, Korba et al. 2020). The technology can save setup and running cost of AMI by optimizing the number of gateways and using specified low power radio communication technologies such as ZigBee (Dileep 2020). However, multihop wireless networks suffer from reduced quality of service and unfairness in getting transmission opportunities among the smart meters.

The authors in Maamar and Benahmed (2019) and Kowshik et al. (2020) discuss the optimal scheduling of random access periods and the effect of mobility of smart meters across the AMI network coverage. These previous works, however, considered only single-hop models and do not take multihop topology into consideration. Therefore, they do not represent actual network scenarios in the ever-expanding smart grid networks.

A fundamental challenge of multi-access communications is how to efficiently share the channel resources among multiple users. From advocates of Linux open-source Hawaii association (ALOHA) to IEEE 802.11 Wi-Fi networks, random access has proven to be a simple yet elegant solution (Ahmetoglu et al. 2021). The minimum coordination and distributed control enable it to become one of the most widely deployed network technologies today (Malachi and Cohen 2020). Different aspects can be studied to achieve this goal from the networking perspective.

Similarly, previous research showed that the smart meter-gateway arrangement in wireless mesh networks (WMNs) can have a significant impact on the network throughput (Kabir et al. 2021), however, finding the solution for the physical smart meter-gateway arrangement is challenging (Roy and Khan 2019). In this paper, we focus on smart grid features that can reduce delay and improve throughput. This paper proposes a resource efficient logical model and derives associated mathematical models, based on queuing and random access models, to mimic the AMI network. The model performance is evaluated using MATLAB® simulation.

Materials and Methods

AMI architecture

It is assumed that each smart meter in a NAN or Field Area Network (FAN) is equipped with IEEE802.11s and forms a mesh network rooted at a gateway (Roy and Khan 2019, Kabir et al. 2021). The gateway connects to the utility company through WAN using public networks, fiber or power line communication (PLC) as depicted in Figure 1 (Al-Waisi and Agyeman 2018). Figure 2, shows actual IEEE 802.11s links of smart meters, forming the multi-hop network as they communicate with one another. As the mesh root node, the gateway collects the network topology information, establishes and maintains paths to all smart meters in the network. In this work, smart meters are used for periodic remote meter reading only (Le at al. 2016). It is also assumed that each smart meter supports a wide range of data collection frequencies that can be configured remotely (Dugaev and Siemens 2014). The meter reading frequency may vary from one utility to another and the type of the consumers. For residential customers, it is distributed from 1 to 60 minutes, while for commercial or industrial buildings, consumption data can be collected in seconds. However, it is not uncommon to collect meter data from 5 to 30 seconds for large consumers. Each smart meter type has different requirements in terms of revenue billing data and operational data (Maamar and Benahmed 2019).

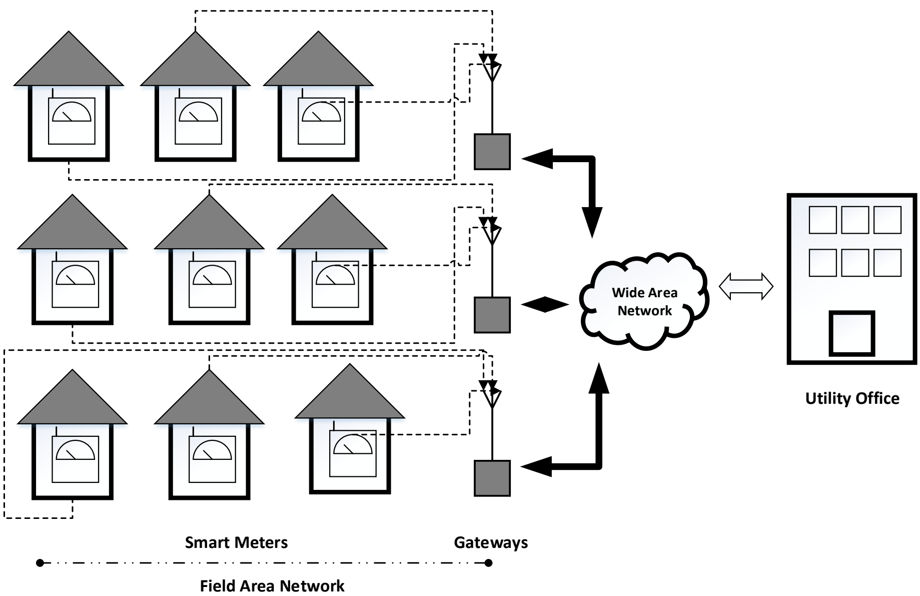

Figure 1: AMI architecture.

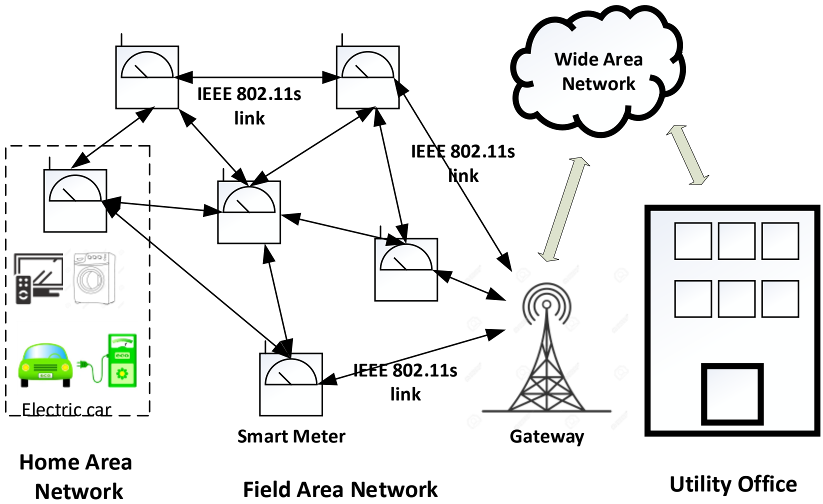

Figure 2: IEEE 8802.11s based AMI architecture.

Resource Efficient AMI model

The main challenge in modeling a physical system is in choosing a model that has on the one hand enough complexity to capture the complexity of the phenomena in question, but has on the other hand enough structure and simplicity to allow computation of the things of interest. Known from the facts that AMI can be used to accommodate different services like demand side management, demand response, monitoring and control functions form the utility, the massive exchange of data and signaling calls for efficient methods to utilize network resources (Khan et al. 2020, Park and Son 2020, Salim et al. 2020). The wireless sensor clustering network structure in Figure 2 supports this fact as the network nodes increase the demand for bandwidth to transmit data and control signals. The smart meters, of which in this context will be referred to as nodes, receive and send data in a random fashion. Therefore, in order to model AMI data transmission mechanism, several assumptions are put forward as following: sensor nodes only detect genuine data which arrives according to Poisson distribution, each sensor node shares the same detecting capability, data waits in shared queue evenly, and data can be transmitted from the source node to gateway through multi-hops. The multi-hop data transmission mechanism is a queuing system in which the generation and arrival of data in the nodes is independent, stationary random process. Also, the data interval time is random and stationary. Hence, the arriving data will form a queue prior to being forwarded. In this queuing service system, data arrival at the node becomes an input process and the nodes forwarding data are service agents. In terms of queuing theory, when detected data in each node follows Poisson distribution and the time of forwarding data by the node follows negative exponential distribution, then data arrival and forwarding process form a birth-death process.

In this work, queuing and random accesses protocols in logical AMI model are used in modeling a hybrid communication system with the above-mentioned transmission scheduling. Figure 3 shows the logical topology of the proposed hybrid multi-hop AMI model with the nodes being multi-queued to a single server (gateway). Each queue consists of M nodes and the queues are grouped into h levels where $1 \le h \le H$.

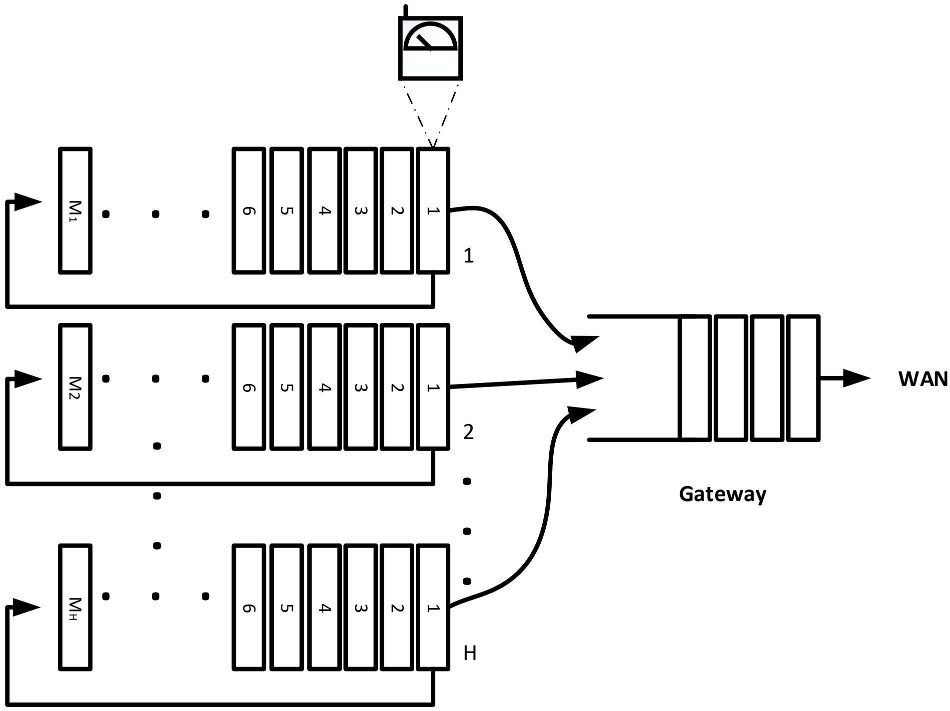

Figure 3: Proposed logical AMI model.

Each node is scheduled to transmit consumption data in time T , and in each time unit the nodes and AMI system may transmit other types of traffic. Time units are divided into queuing (T_Q) and random-access (T_{CS}) periods, dedicated for transmissions with relevant protocols as shown in Figure 4. The queuing protocol is used for the purpose of avoiding collision in periodical transmission to and from the nodes. The nodes are queued sequentially by the gateways which enables contention-free communication. Slotted ALOHA is adopted in random access periods which is divided into slots and each node randomly and independently chooses a slot for its transmission. If a slot is selected by only one meter in a given queue, transmission succeeds. In contrast, if two or more meters transmit packets simultaneously in the slot, all the transmissions there fail because of collision.

Data transmission paths from nodes to a gateway form a queue system with the gateway as a root in AMI. Every node transmits its own data and relays data from its neighbors to a gateway. Nodes try to transmit their own data to their neighbors in a slot and feedforward data received from their neighbors randomly in the next slots. From Figure 4, the queuing and random-access time are represented as

$$T = T_Q + T_{CS} \qquad 1$$

The random-access time is divided into time slots equal to the number of nodes in a given level. The time slot duration is represented as t_{cs}. The random-access time is given as;

$$T_{CS} = M.t_{CS} \qquad 2$$

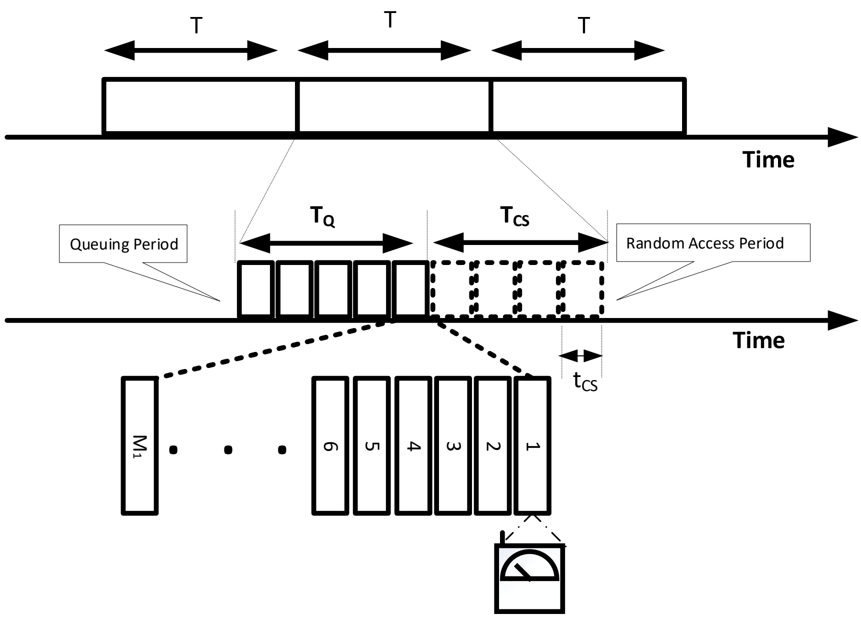

Figure 4: Queuing and random-access timing.

Model description

The model in Figure 3 is considered as a system of H finite-size queues of smart meters, $Q_1, Q_2, Q_3, ..., Q_H$. Each smart meter generates a packet with probability λ_i in queue Q_i and no packet is generated in the presence of the transmitted packet. It is also assumed that smart meters conduct packet aggregation upon receiving packets from the child meter. The service time at Q_i is an independent random variable μ_i with first and second moments $E[\mu_i]$ and $E[\mu_i^2]$, respectively. The Laplace–Stieltjes transform (LST) of the service time is taken as $\xi_i(s)$ where s is a complex variable. The offered load to this queue is $\rho_i = \lambda_i E[\mu_i]$ and the total system load, ρ, is given as

$$\rho = \sum_{i=1}^{H} \rho_i \qquad 3$$

In this work, it is assumed that the service time parameters are identical in all queues. This is translated as $\xi_i(s) = \xi(s)$, $E[\mu_i] = E[\mu]$ and $E[\mu_i^2] = E[\mu^2]$. The gateway selects the queues in a cyclic order when leaving Q_i, and before moving to the next queue there is a switch-over period whose duration is a random variable r_i with first two moments $E[r_i]$ and $E[r_i^2]$. The total switch-over time, r, in a cycle is given as

$$r = \sum_{i=1}^{H} r_i \qquad 4$$

The switch-over time is distributed over queuing time T_Q divided into H slots. The service discipline in all queues is assumed to be gated service in which when the gateway selects Q_i it serves all the smart meters at the beginning of the random access period.

At the beginning of a random access period, each meter randomly chooses one of M slots in the period and transmits a packet to its parent meter. All the transmissions fail due to collision if two or more meters having the same parent transmit their packets in a slot, and unsuccessful transmission requests wait until the next random access period begins. A meter receiving packets from its neighbor forwards them in the next slot, but they are discarded when collision occurs.

In this work, we assume that the system is perfectly synchronized so that the waiting time is the only delay in the system. Let ω_i be the waiting time probability distribution at Q_i and ω be the waiting time of an arbitrary smart meter. In steady-state distributions, the wait time in an M/M/1 queue is given as

$$\omega_i(t) = 1 - \rho e^{-\mu_i(1-\rho)t} \qquad 5$$

where is the i^{th} state (queue depth) at time t.

The Laplace–Stieltjes transform (LST) of ω_i can be derived from numerical procedures from $\lambda_j\ (j = 1,2,....., H)$, $\xi(s)$ and $r_j\ (j = 1,2,....H)$. The pseudo-conservation law is derived as

$$\sum_{i=1}^{H} \rho_i E[\omega_i] = \rho \frac{\sum_{i=1}^{H} \lambda_i E[\mu_i^2]}{2(1-\rho)} + \frac{\rho}{2r}\left[r^2 + \sum E[r_i^2] - E[r_i]^2\right] + \frac{r}{2(1-\rho)}\left[\rho^2 + \sum_{i \in g} \rho_i^2\right] \qquad 6$$

where $i \in g$ relates to all queues in which the service is gated. In the proposed system, the service time distribution is identical for all queues. In this case $E[\mu_i] = E[\mu]$ and $\rho_i = \lambda_i E[\mu]$, we can use equation 6 to derive the mean waiting time of an arbitrary smart meter (packet) in the system as

$$E[\omega] = \sum_{i=1}^{H} \frac{\lambda_i}{\lambda} E[\omega_i] = \frac{\sum_{i=1}^{H} \lambda_i E[\mu_i^2]}{2(1-\rho)} + \frac{E[r]}{2r} + \frac{r}{2(1-\rho)}\left[\rho^2 + \sum_{i \in g} \rho_i^2\right] \qquad 7$$

Let ψ denote the successful arrival of a packet at the gateway. The distribution function of the transmission delay is defined as

$$F_i(t) = \Pr(\omega_i \le t, \psi) \qquad 8$$

From the property of the LST, successful transmission probability, Y_i^s, is given as

$$Y_i^s = F_i^*(0) \qquad 9$$

Where the LST of $F(t)$ is given as

$$L^*\{F(t)\} = F^*(s) = \int_0^\infty e^{-st} dF(t) \qquad 10$$

For our purpose, we consider $F(t)$ to be the cumulative distribution function (CDF) of nonnegative random variable X, as

$$F^*(s) = E[e^{-sX}] = \int_0^\infty e^{-st} dF(t) \qquad 11$$

It is known that $\omega_i(t)$ does not have a PDF at $t = 0$, because $\omega_i(t)$ is discontinuous. In particular, $\omega_i(0^-) = 0$, while $\omega_i(0) = 1 - \rho$, so there is a point mass of probability $(1-\rho)$ at $t = 0$. In other words, with probability $(1-\rho)$ the ith queue's wait is *exactly* zero. Therefore, to derive $F_i^*(s)$, we have to consider:

i. The transmitted packet from the ith smart meter is successful transmitted in the random access period and received by the gateway with probability $\prod_{i=1}^{m}(1-\chi_i)$. The failed transmission is represented by χ_i for the packet in the ith smart meter.
ii. The transmission of a packet is unsuccessful χ_i

The former consideration indicates that a packet must wait $(m-1)t_{CS}$ until its transmission is started if the m^{th} slot $(1 \le m \le M)$ is chosen in the queue of M smart meters. The packet takes

$m.t_{CS}$ to be received by the gateway. The smart meter chooses one of the M slots with probability $\frac{1}{M}$ in the transmission of the respective packet. The gateway also cyclically chooses the queues for transmission with probability $\frac{1}{H}$. The latter consideration indicates that a smart meter should wait another T frame time until its retransmission begins. The LST of the delay distribution is now given as

$$F_i^*(s) = \prod_{i=1}^{m}(1-\chi_i)\cdot\frac{1}{H}\cdot\frac{1}{M}\sum_{m=1}^{M} e^{-s(2m-1)t_{CS}} + \chi_i . e^{-sT} . F_i^*(s) \qquad 12$$

Solving for the LST of delay distribution in equation 12 gives

$$F_i^*(s) = \frac{\prod_{i=1}^{m}(1-\chi_i)\cdot\sum_{m=1}^{M} e^{-s(2m-1)t_{CS}}}{MH(1-\chi_i . e^{-sT})} \qquad 13$$

Throughput analysis

The throughput for a queuing system with infinite capacity is the mean number of packets transmitted in a unit of time. In this work, we define throughput of a meter in the h^{th} queue, θ_h as the mean number of packets per slot which are generated at the node and successfully received by the gateway. Total throughput Θ will be the sum of all N_{Total} meters representing the performance of the network.

Let ϕ_h denote the transmission probability of a meter in h^{th} queue for an arbitrary slot. The transmission could be own packet, forwarding packets from neighbor or transmission of its own and descendants' packet. At the beginning of the n^{th} random access period, the possible states of the meter can be represented by stochastic variable $\{X\}$. If the meter has a packet the state is $\{X^1\}$ and if the meter has no packet the state is $\{X^0\}$. Therefore, the meter state could be represented as

$$X^1 = \{no\ packet.\ generate\}\ or\ \{has\ packet.\ fail\ to\ transmit\}\ or\ \{no\ packet.receive\ from\ descendants\} \qquad 14$$

$$X^0 = \{has\ packet.transmit\}\ or\ \{has\ no\ packet.\ fail\ to\ generate\}\ or\ \{receive\ from\ descendants.\ transmit\} \qquad 15$$

These states can be represented into a transition diagram as shown in Figure 5. The transition is governed by the generation, successful transmission and failed transmission probabilities.

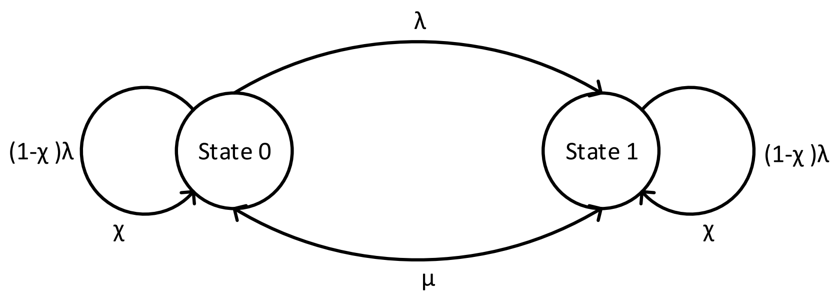

Figure 5: Transition state diagram.

The probability of failed transmission is represented by χ and defined as

$$\chi = 1 - \left(1 - \phi_h\right)^{M_{h-1} - 1} \tag{16}$$

The transition state diagram in Figure 5 represents a discrete Markov chain process and the associated stationary state transition matrix can be deduced as

$$P = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P11 \end{bmatrix} = \begin{bmatrix} \chi + (1-\chi)\lambda & \lambda \\ \mu & \chi + (1-\chi)\lambda \end{bmatrix} \tag{17}$$

where P_{ij} is the probability of transiting from state *i* to state *j*.
From Markov chain theory, we note that

$$X^n = PX^{n-1} \tag{18}$$

Therefore, if we let $\lim_{n \to \infty} X^n = \pi$, we obtain

$$\pi = \lim_{n \to \infty} X^n = \lim_{n \to \infty} PX^{n-1} = P\pi \tag{19}$$

Definition 1: A vector $\pi = \left(\pi_0, \pi_1, ..., \pi_{K-1}\right)^t$ is said to be a stationary distribution of a finite Markov chain if it satisfies

$$\pi_i \geq 0 \text{ and } \sum_{i=0}^{K-1} \pi_i = 1 \tag{20}$$

$$P\pi = \pi \text{ and } \sum_{j=0}^{K-1} P_{ij} \pi_i = \pi_i \tag{21}$$

Definition 1 indicates that, for any irreducible and aperiodic Markov chain having *K* states, there exists at least one stationary distribution. From the transition matrix in equation 17, the stationary distribution for the two states $\left(\pi_0, \pi_1\right)$ are given as 22

$$\begin{cases} \left(\chi + (1-\chi)\lambda\right)\pi_0 + \mu\pi_1 = \pi_0 \\ \lambda\pi_0 + \left(\chi + (1-\chi)\lambda\right)\pi_1 = \pi_1 \\ \pi_0 + \pi_1 = 1 \end{cases} \tag{22}$$

From the stationary state distributions $\left(\pi_0, \pi_1\right)$, we obtain 23

$$\begin{cases} \pi_0 = \dfrac{\mu}{1 + \mu - \lambda - \chi(1-\lambda)} \\ \\ \pi_1 = \dfrac{\lambda}{1 - \chi(1-\lambda)} \end{cases} \tag{23}$$

Using the expressions in equation 23, the probability of successful transmission can be expressed as 24.

$$\phi_h = \begin{cases} \frac{1}{H}\cdot\frac{1}{M}\frac{\lambda}{\{1-\chi_h(1-\lambda)\}} + \left[1-\frac{1}{H}\cdot\frac{1}{M}\frac{\lambda}{\chi_h(1-\lambda)}\right].N_h\phi_{h+1}(1-\phi_{h+1})^{N_{h+1}}, 1 \le h \le H-1 \\ \frac{1}{H}\cdot\frac{1}{M}\cdot\frac{\lambda}{1-\chi_h(1-\lambda)}, h = H \end{cases} \quad 24$$

Using the first term of the expression in equation 24, the probability of the m^{th} smart meter in a queue transmitting a packet is given as

$$p_m = \frac{\pi_m^1}{H.M} = \frac{\lambda}{H.M\{1-\chi_m(1-\lambda)\}} \quad 25$$

The throughput of the smart meter is now given as 26.

$$\theta_m = p_m \prod_{i=1}^{m}(1-\chi_i) \quad 26$$

The total throughput in the network is given by 27.

$$\Theta = \sum_{m=1}^{H} M_m \theta_m \quad 27$$

Results and Discussion

In this section, the results obtained through numerical analysis and simulations are presented. To evaluate the performance of the proposed AMI model, the parameters shown in Table 1 were used. The performance parameters of interest are delay and throughput. We started by reviewing the tail probabilities of delay as the number of queues increases at constant λ, μ and r.

Table 1: System parameters for analysis

Parameter	Value
Total number of smart meters N_{Total}	500
Total number of smart meters in a queue	50
Length of a frame T [sec]	200
Duration of queuing time T_Q [sec]	100
Duration of a random access period T_{CS} [sec]	100
Number of slots M	50
Length of a slot t_{CS} [sec]	0.5
Service time rate μ	0.1-1.0
Packet generation probability λ	0.1-1.0

We use equation (7) and the numerical method presented in Konheim et al. (1994) to analyze the delay performance of the system. We derived the value of $\Pr[\omega > t]$ for a given $t > 0$ and then compared with numerical techniques for different scenarios. The packet generation rate of each queue is $\lambda_i = 0.95$ and the service time has a bimodal distribution with $\Pr[\mu = 0.008] = 0.99$ and $\Pr[\mu = 0.25] = 0.001$ (thus $E[\mu] = 0.0082$ and $\rho = 0.78$). This reflects a system in which the normal transmission time of a packet is in the order of milliseconds; while occasionally a large amount of processing is required (thus increasing the variability of service time). The switch-over periods are identically distributed for all queues and are bimodal with $\Pr[r_i = 0.0005] = 0.99$ and

$\Pr[r_i = 2.2] = 0.01$. This reflects a normal switch between the queues which takes less than a millisecond. In Figure 6, we observe that at a fixed switchover rate, the systems with higher number queues perform better than a single queue system due to the fact that the gateway will try to serve empty switchover slots in the queuing time. As the selection of queue is cyclic, the gateway will rotate $(H-1)$ times before reselecting the same queue. This extends the average waiting time of the smart meters in the single queue system using the model in Figure 3.

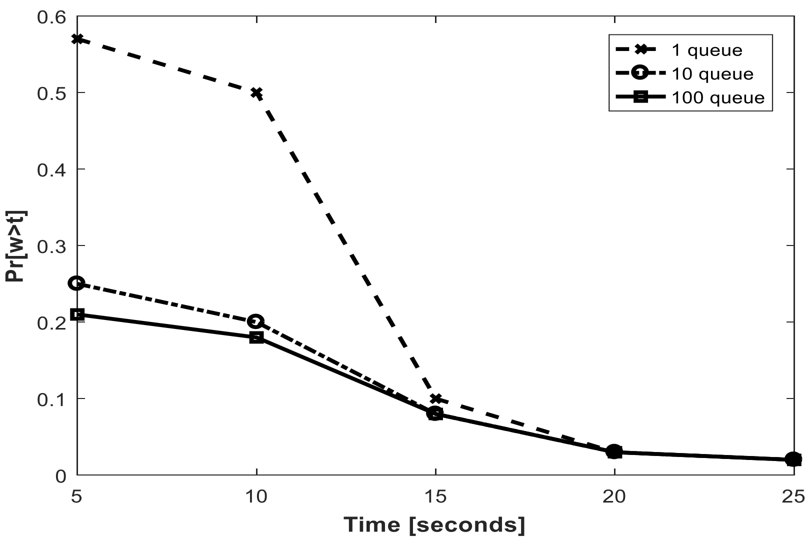

Figure 6: Variation of delay tail probability with time.

At $\Pr[t > 15]$ the systems saturate by reaching a steady and the waiting time is dominated only by the packet transmission rate μ and the loading effect ρ at fixed switch-over rate. In Figure 7, the number of queues is increased to 300. The delay performance demonstrates that the 200 and 300 queue systems are slightly sensitive to the switchover periods at lower values of t and saturates at $t > 15$. This portrays similar delay performance with 10 and 100 queue systems. This fact is explained from the principles of merging queues of different lengths but similar loading. For gated queues, the mean delay decreases as the number of queues increases at constant switch-over periods. At steady-state, the queues are observed as one queue of data packets. It should be noted that the non-existence of acknowledgement messages saves time in the listening and feedback process practiced in most polling protocols.

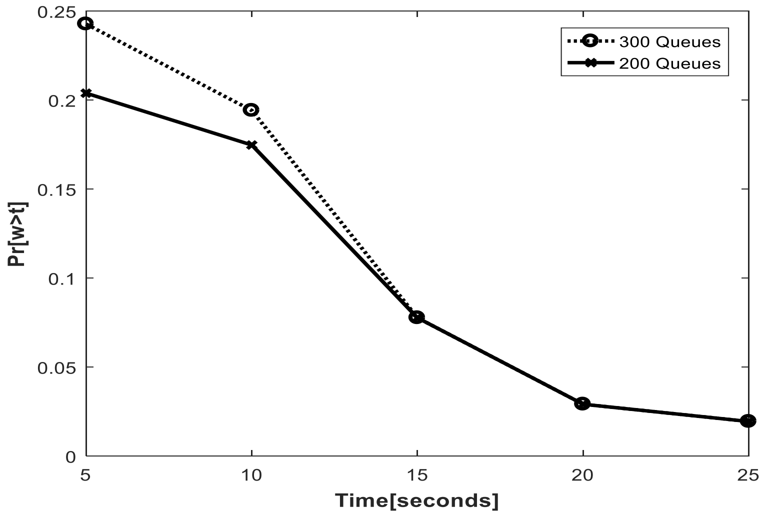

Figure 7: Variation of delay tail probability with time for large number of queues.

The throughput performance of the system is evaluated in Figure 8. The system is evaluated at 1 and 10 queues. The performance indicates that for single queued system total throughput is high when λ is low, but decreases as λ gets larger. From the assumptions made in the model in Figure 3, that smart meters can also transmit their neighbor packets together, the total throughput increases as the number of queues increases.

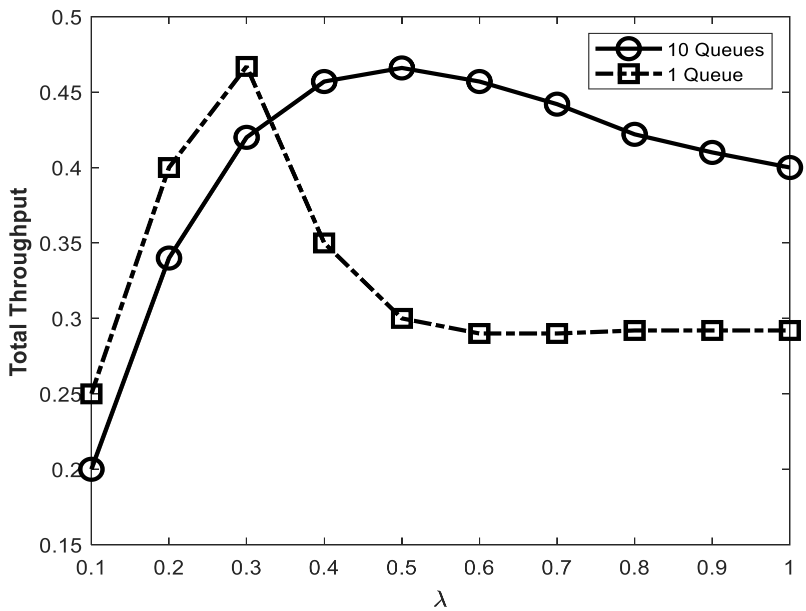

Figure 8: Variation of throughput with packet generation rate.

In Figure 9, the throughput of the proposed system is compared with existing method presented in Matsuzawa and Takahashi (2016). It is observed that a single queue system demonstrates similar throughput performance as the existing method when all the smart meters are located in the same depth.

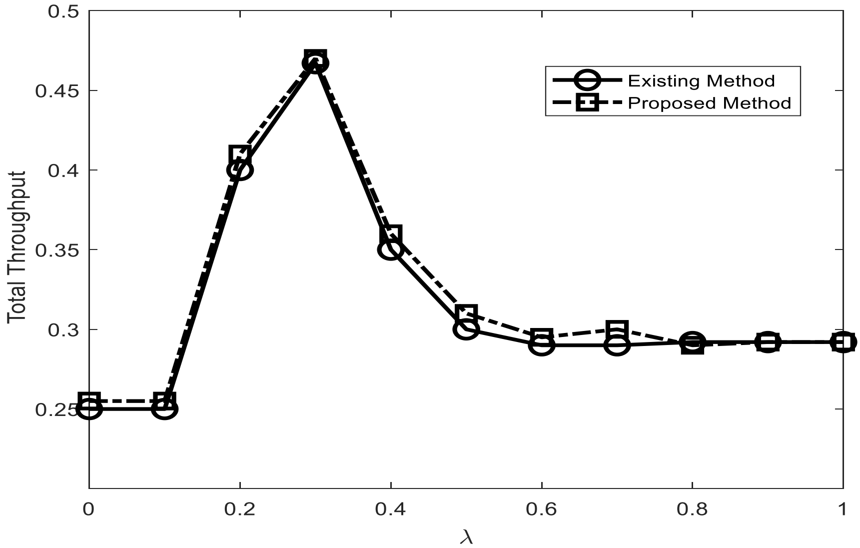

Figure 9: Variation of throughput with packet generation rate.

In Figure 10, the total throughput is evaluated as the number of queues increases. It is observed that the total throughput increases as the number of queues increases due to decrease in the collision probability at lower values of λ. As the value of λ increases, the probability of collision increases, and therefore, the total throughput starts to deteriorate. It is observed that there is a 10% improvement in throughput performance of the 500-queue system compared to the existing system when the package generation probability is maximum.

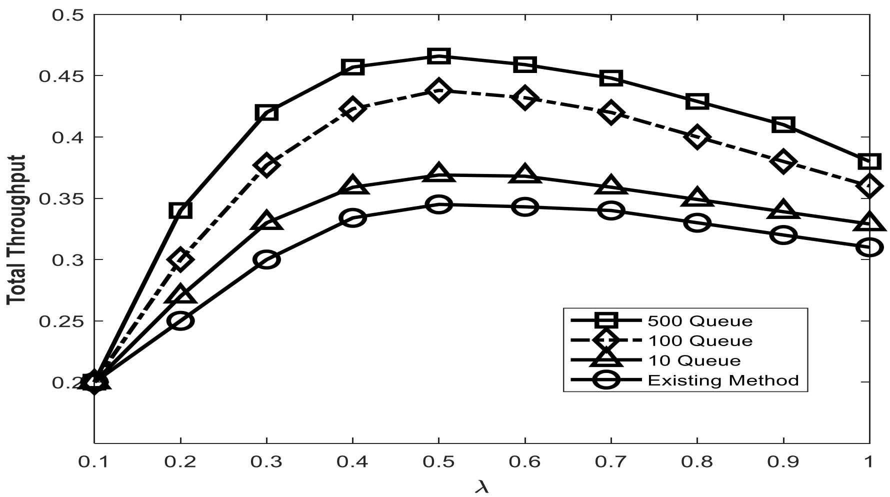

Figure 10: Total throughput with packet generation at different queue sizes.

We estimated the actual delay for different number of queues. It is observed in Figure 11 that for single queue arrangement, the proposed method demonstrates similar delay performance with existing systems. The number of smart meters increased to 500 and the mean delay is observed to increase as the packet generation rate λ increases. At $\lambda = 0.6$, the delay of the proposed method with 500 smart meters, is improved by 15% compared to the existing method with 500 smart meters. The deterioration of delay performance at higher values of λ is due to the fact that probability of collision increases as λ increases.

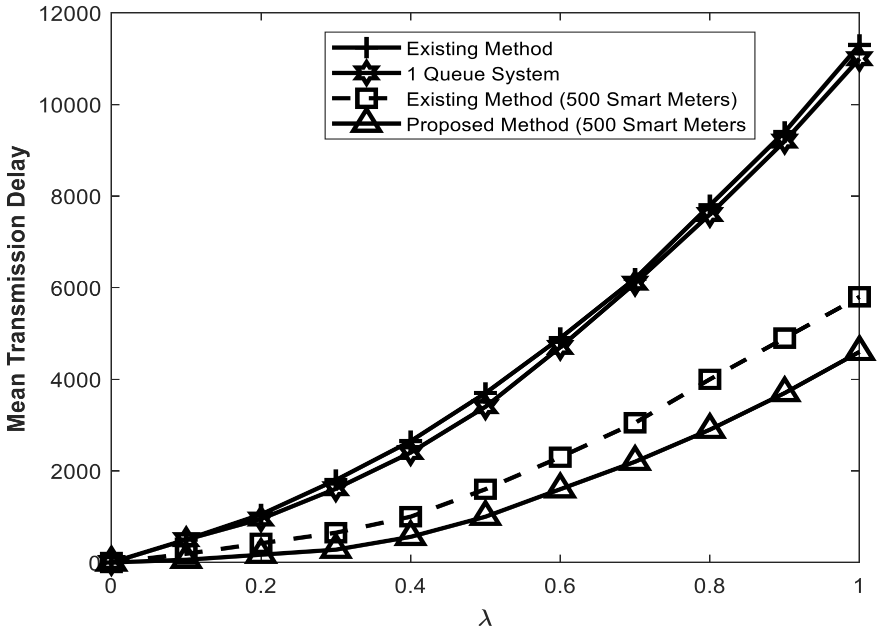

Figure 11: Mean transmission delay vs packet generation.

Conclusion

The Advanced Metering Infrastructure plays a critical role in the smart grid. In regarding the usage of smart meters in the AMI, there is a primary concern about how utility companies manage the ever increasing demands of transmission bandwidth for not only smart meters but mushrooming of smart devices, sensors and support applications technologies. To cope with this challenge, the utility companies could overhaul their information networks or adopt efficient network modeling to support the communication needs of the smart devices. In this paper, the latter has been chosen as a practical solution. In this paper, we considered the effect of the configuration of network topology on the performance of AMI with the hybrid communication protocols. The model used queuing and random access protocols. Then, a mathematical model of AMI is developed taking into consideration the performance parameters of throughput and the transmission delay.

From numerical analysis, it was found that the delay performance of the entire network can be improved by constructing a large queue system at fixed switchover time. It was observed that throughput performance stabilized at lower values of packet generation rates for gated queue systems. So, our future work is to compare the performance of the gated queue system with exhaustive service discipline at variable queuing time.

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