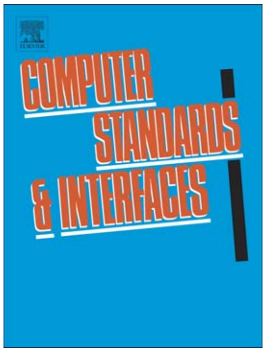

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A Novel Data Collection Mechanism for Smart Grids Using Public Transportation Buses

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Abstract

In this study, we propose a novel solution for collecting smart meter data by merging Vehicular Ad-Hoc Networks (VANET) and smart grid communication technologies. In our proposed mechanism, Vehicular Ad-Hoc Networks are utilized for collecting data from smart meters, eliminating the need for manpower. To the best of our knowledge, this is the first study proposing the utilization of public transportation vehicles for collecting data from smart meters. With this work, the use of the IEEE 802.11p protocol has been proposed for the first time for use in smart grid applications. In our scheme, data flows first from smart meters to a bus through infrastructure-to-vehicle (I2V) communication and then from the bus to a bus stop through vehicle-to-infrastructure (V2I) communication. The performance of our proposed mechanism has been investigated in detail in terms of end-to-end delay and delivery ratio by using Network Simulator-2 and with different routing protocols.

Keywords:
ns-2, smart grids, VANET, V2I, V2V, WAMR

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1. Introduction

With the advances in wireless communication technology, it has been used in many areas, including environmental monitoring, health-related, home,

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industrial, military and surveillance applications, smart grid and vehicular communications [1]. Wireless communication helps reduce wired installation costs for many applications. The collaborative nature and low-cost features of wireless communication help its widespread adoption in different areas.

The smart grid technology is a new concept for the next generation electric power system and it is the modernized version of the traditional power grid of the 20th century [2, 3, 4]. The smart grid technology enables real-time monitoring, protection and self-healing for grid elements. Furthermore, it permits two-way communication for the flow of both electricity and information. One of the vital components of a smart grid system is the Advanced Metering Infrastructure (AMI) technology [2], [5, 6]. Smart meters enable two way communications between utilities and consumers using the AMI technology. With the help of the AMI technology, utilities can collect timely data on energy consumption, power quality and load profiles of their customers. In addition, utilities do not need to hire staff to manually collect consumption data from meters since smart meters automatically transmit this data to the utility center. With the AMI technology, customers can be informed on how much power they used and notified about critical periods of peak pricing. The existing applications of smart grids include automatic metering, demand response, distribution automation, fault diagnostics, load control and power fraud detection [4], [7].

Vehicular communication is the vital technology in Intelligent Transportation Systems (ITS) for improving road safety and comfort [8]. Recently, it has been reported as one of the most important technologies used in vehicles [9]. The vehicular communication technology is also known as Vehicular Ad Hoc Networks (VANETs) which is an extension of Mobile Ad Hoc Networks (MANETs) to vehicles. VANETs have special features compared to MANETs, including high and predictable mobility, large scale usage, partitioned networks and variable topology [10]. In VANETs there are two types of communication which are vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). The first one represents the communication between vehicles and the second one between vehicles and Road-Side Units (RSUs). The Dedicated Short-Range Communication (DSRC) or IEEE 802.11p communication protocols are the communication protocols used in research and development studies for VANETs [11]. The IEEE 802.11p protocol is an extension of the existing widely used IEEE 802.11 protocol with some amendments on MAC and physical layer for VANETs. It is based on the Orthogonal Frequency-Division Multiplexing (OFDM) technique on the physical layer. IEEE 802.11p has 6-27 Mbps data rate with 10 MHz bandwidth and 1000 m communication range [9], [12]. The existing applications of vehicular communication are weather-related information alerts, blind spot warning, do-not-pass warning at intersections, emergency vehicle warning, forward collision/accident warning and lane change warning [10], [12, 13].

In this paper, we first explored the existing mechanisms for collecting data from smart meters in a smart grid, and then proposed a new one which is based on VANETs. Our proposed mechanism is a novel solution for data collection from smart meters and includes public transportation buses. The main contributions of our study are listed below:

- To the best of our knowledge, there is no published work which uses public transportation vehicles for collecting data from smart meters. This is the first study in this field.
- Our proposed mechanism only needs the IEEE 802.11p communication protocol capability on Wireless Automatic Meter Reading (WAMR) systems. This communication protocol may extend the communication range of smart meters up to 1000 m and it will be used for the first time in the literature for smart grid applications.
- Unlike other vehicular communication schemes, our study uses both I2V and V2I communication. Data first flows from smart meters to a bus, which is through I2V communication, and then from the bus to a bus stop, which is through V2I communication.

The remainder of this paper is organized as follows. In Section 2, an overview of the existing mechanisms for data collection from smart meters are presented. In Section 3, our proposed scheme is introduced. In Section 4, the system model is introduced. In Section 5, the performance evaluations of our proposed scheme are presented. Finally, Section 6 is the conclusion.

2. Related Work

The existing traditional electric meters do not have the capability to send their data to the utility company. Because of this problem, utilities have to hire employees and send them to houses to read meters manually. The problems in this data collection model are the availability of limited hours to read meters and the dependency on householders (if there is no one in a building, the employee of the utility company cannot enter the building to read meters). Furthermore, since there is no two way communication in the existing traditional electric grid, utilities cannot learn actual demand on peak and non-peak hours.

In literature, there are many existing studies on WAMR systems. Since they enable two-way communication, they allow utilities to get timely electricity consumption data which helps detect and prevent illegal electricity usage. Moreover, meter reading expenses of utilities are reduced since they do not need to hire employees to read meters. There exist four different types of Automatic Meter Reading (AMR) systems, given as follows:

- Drive by AMR systems
- Fixed network AMR systems
- Touch based AMR systems
- Walk by AMR systems

In drive by AMR systems, a utility company personnel drives by all the streets where it has customers. This means extra cost for utility companies since they need vehicle, gas and etc. In fixed network AMR systems, there is an initial setup cost for setting up a permanent network. In touch based AMR systems, if there is no one at the building at the time of scheduled measurement, the utility company cannot get in the building and get information from the meters in that building. In walk by AMR systems, a utility personnel has to go inside each building to read meters and this takes too much time. Except fixed network AMR systems, all others systems require an employee to read meters. This causes increased expenses for utilities. In addition, these three AMR systems cannot give timely information to utilities. Our proposed data collection mechanism does not need any utility personnel for reading meters which helps utilities reduce their operating costs. In addition, our solution helps utilities get timely information from meters. Thus, utilities can predict users' future electricity consumption more realistically. A comparison of existing AMR systems is shown in Table 1.

The existing technologies that are used for data communication in AMR systems are Power Line Communication (PLC), messaging over a GSM network, telephone line and short range Radio Frequency (RF) [14]. In PLC, voltage transmission lines are used to transmit data. The meters transmit

Table 1: Comparison of AMR Systems

	Drive by AMR	Fixed Network AMR	Touch based AMR	Walk by AMR	Our Solution
Less Cost	×	×	×	×	✓
Less Personnel	×	✓	×	×	✓
Initial Setup Cost	✓	✓	✓	✓	✓
Timely Measurements	×	✓	×	×	✓
Precise Measurements	×	✓	×	×	✓

their data to PLC modems via the wireless or wired channels and these modems transmit data to the utility company using electric transmission lines [15, 16, 17, 18]. In messaging over a GSM network, a GSM modem is installed on the meter and all data is transmitted via SMS to the utility company [19, 20, 21]. In telephone lines, it is assumed that each meter is equipped with a telephone line and data is transmitted via the telephone network in both directions [22, 23]. In RF, existing electricity meters are equipped with Bluetooth, Wi-Fi or ZigBee, and they transmit their data to a base station in a hop-by-hop fashion. All data collected on the base station is transmitted to the utility company using a dial-up connection or it is collected by an employee [24, 25, 26].

In [27], the authors introduced the applications for smart meter data collection in a smart grid. They also proposed a solution to improve the transmission rate of a Data Aggregator Unit (DAU). The data in smart meters are transmitted to a DAU through a Neighborhood Area Network (NAN) via Wi-Fi and the DAU transmits the collected data to a Meter Data Management System (MDMS) through a WAN via WiMAX.

In [28], the authors designed a wireless GSM enabled energy meter. They also built a web site for automating billing and managing the collected data globally. In their system, meters have GSM connection and thus utilities can monitor them regularly. The data collected at smart meters are periodically transmitted to the utility company and at the utility side a GSM receiver gets the data and writes it to a central database to update the consumption. In the proposed system, the data is processed in three steps as follows: 1) A digital GSM enabled power meter reads electricity consumption data, 2) The electricity consumption data is transmitted via SMS to the utility company, 3) The electricity consumption data is received and processed by the billing server of the utility company.

In [29], the authors proposed a hybrid cooperation scheme for smart meters. In the proposed method, smart meters transmit their data to a base station using a short-distance communication technology such as Wi-Fi, ZigBee, Bluetooth, etc. And then, the base station uses the LTE technology to transmit the data to the utility company.

In [30], the authors proposed a cost effective novel approach for AMR systems in rural areas. Instead of hiring people for meter reading, they offered using unmanned vehicles with GPS capability. They used the IEEE 802.15.4 communication protocol for their AMR system. They also made some simulations for the lifetime of battery used in WSN nodes. According to their performance evaluations, their proposed method is well suited for wide areas with few customers.

In [31], the authors designed and implemented a WAMR system. They added wireless modules to existing meters by using the ZigBee [32] communication protocol. Since they used ZigBee communication, their proposed hardware has short-range and low-power wireless technology. In their proposed study, wireless modules are connected to meters through RS-485 buses. These wireless data collecting modules transmit their data to a sink node individually or through multi-hop communication in a hop-by-hop fashion. And then, on the sink node, the received data is wirelessly transmitted to a server node via an RS-232 bus.

In [33], the authors offered using GSM as the communication medium for WAMR Systems. In the suggested mechanism, meters transmit their information, including electricity usage, power quality and outage alarm, to the utility company, and at the end of each month, the utility suggested method would facilitate the generation of bills which will be sent to customers via SMS or e-mail.

Although all the mentioned studies in literature have made important amendments on existing AMR systems or proposed different data collection mechanisms for smart meters, they have some drawbacks. Many of them require subscription to GSM or telephone line service, and some require installations and cable costs. Furthermore, the existing IEEE 802.15.4 protocol based solutions will not work in long ranges. In addition, since it has low data rate compared to IEEE 802.11p, when the size of transmitted data from smart meters increases or when the utility wants to transmit a large amount of data to its customers, the communication delay will increase significantly. The comparison of the technologies that are currently used in existing AMR systems and in our proposed scheme are shown in Table 2.

Table 2: Communication Technologies for AMR Systems

	Long Communication Range	No Subscription Requirement
ZigBee	×	✓
Bluetooth	×	✓
GSM	✓	×
Telephone Line	✓	×
Cable	×	×
IEEE 802.11p	✓	✓

3. The Proposed Scheme

Almost all bus stops in Istanbul are smart bus stops that have embedded computers which are connected to the Internet through Wi-Fi and other wireless communication modules. In the long avenues of Istanbul, or in any similar city with a large network of smart bus stops, instead of hiring people to collect data from meters, meters with wireless capability may transmit their data to public transportation buses which pass regularly through their neighborhoods. The buses may then transmit their collected data wirelessly to the next bus stop. And the bus stop, with its network connection, transmits the collected smart meter data to the utility company. This proposed scheme would be cost effective and provide a novel solution for transmitting consumer data to the utility company in a timely manner. It may be used for transmitting data related to billing, load-balancing or any other smart meter functionality. Since bus stops in Istanbul have Internet and Wi-Fi connection, the proposed system only needs smart meters with IEEE 802.11p communication capability. Likewise, all buses should be equipped with the IEEE 802.11p communication capability.

The proposed data collecting mechanism uses public transportation buses, which has never been used for this purpose before. The data collected by a bus is transmitted to a bus stop. Thus, in our scheme, we combine the vehicular communication technology and the smart grid technology together. As shown in Figure 1, using the IEEE 802.11p communication protocol, our scheme extends the existing WAMR Devices' communication range to up to 1000 m. Smart meters within 1000 m of a public bus can transmit their data to the bus, and the data collected by the bus is transmitted to the bus stop

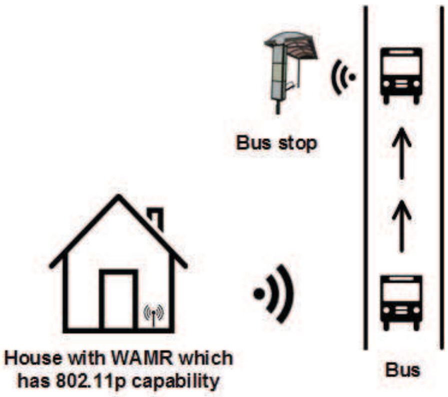


Figure 1: Proposed data collection scheme

when the bus arrives at the bus stop. In the proposed mechanism, bus stops are considered as Road Side Units (RSU) with an embedded processor and network connection to transmit their received smart meter data to the utility company.

To the best of our knowledge, our proposed scheme is the first one in the literature that uses public transportation vehicles for collecting data from smart meters. With this work, the use of the IEEE 802.11p protocol is proposed for the first time in literature for use in smart grid applications. Unlike existing vehicular communication schemes in literature, our study uses both I2V and V2I communication. In our scheme, data flows first from smart meters to a bus through I2V communication and then from the bus to a bus stop through V2I communication.

The advantages of our proposed scheme can be summarized as follows. Since smart meters transmit their data to buses via the wireless channel, utility companies do not need to hire personnel to read this data manually. In addition, since buses operate regularly throughout most of the day, utility companies get electricity consumption data from customers in a timely manner. Moreover, utility companies can also send data, e. g. reconfiguration/update information, to their customers using this scheme.

4. System Model

In this section, we explain our proposed scheme in more detail. In the proposed scheme, houses with smart meters transmit their data, such as electricity consumption information, to buses which pass regularly through their

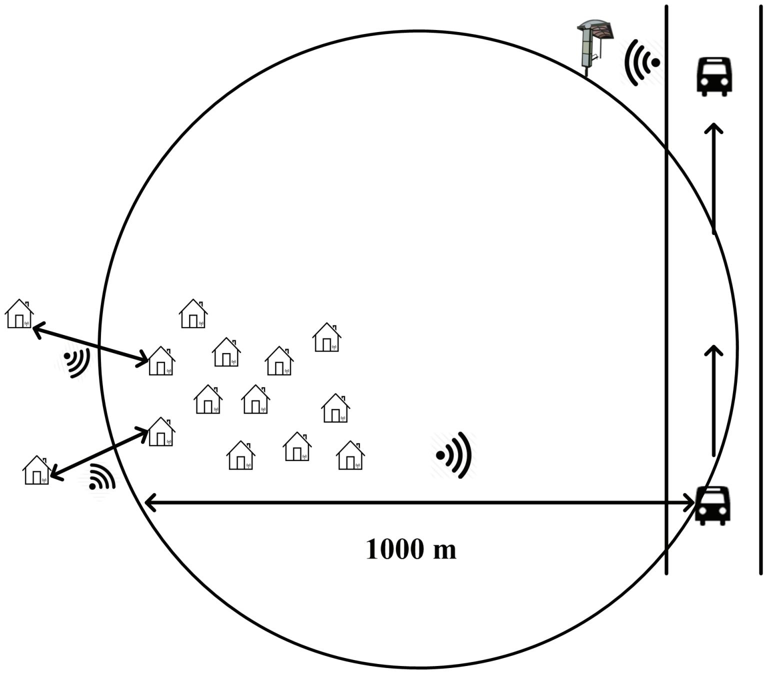


Figure 2: Extended proposed scheme allowing hop-by-hop communication

neighborhoods. After that, the buses transmit the collected data wirelessly to the next bus stop. Finally, the bus stop transmits the collected smart meter data to the utility company. Although, the main concept of the proposed scheme is data collection from smart meters, it also supports two-way communication. For instance, when the utility company wants to transmit information to its customers, such as automatic reconfiguration data, the nearby bus stop can upload this information, which is received from the utility company, to a bus and the bus can transmit this information to the corresponding houses. In the proposed scheme, buses and bus stops are equipped with embedded computers and the buffer size for data transmission is the disc capacity of these embedded computers.

The mechanism mentioned above is most suitable for urban areas. The communication protocol used in our system has a communication range of up to 1000 m. In urban areas, houses are typically covered by streets with running public transportation buses. Houses in rural areas, or houses in urban areas which are more than 1000 m away from a bus line, can also transmit their smart meter data to the bus through intermediary houses

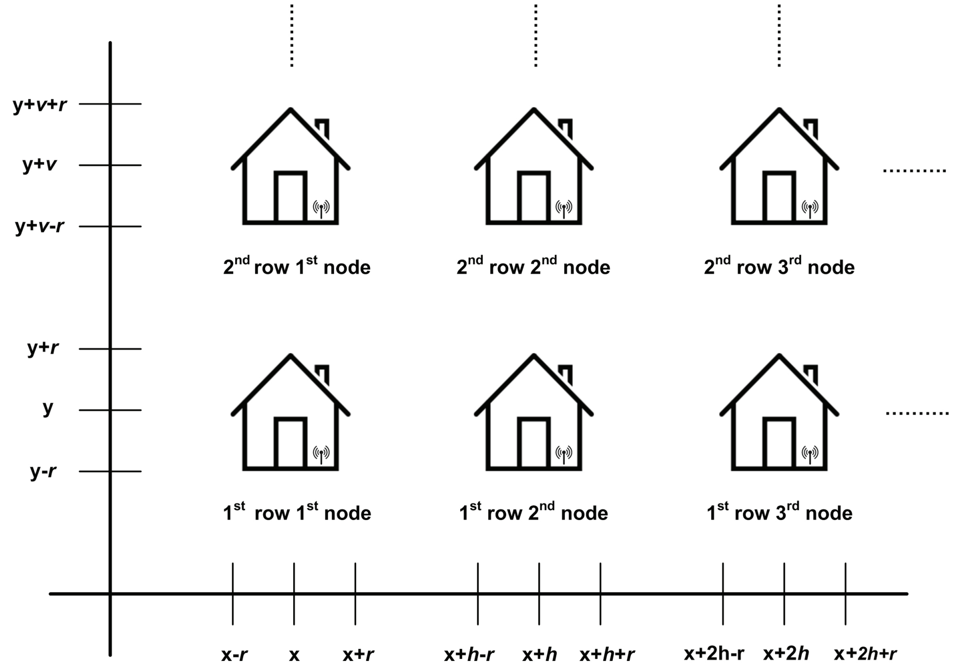


Figure 3: Node placement scenario

with hop-by-hop communication. In this scenario, the last house in the hop-by-hop communication should be within 1000 m far away from the bus road, as shown in Figure 2.

The total number of bus stops in Istanbul is 12396 and 774 of these are smart bus stops. Most of these smart bus stops are placed at central locations. However, the number of smart bus stops are increasing day by day. Therefore, we can assume that the percentage of smart bus stops in Istanbul will increase in the near future to cover significantly larger populations.

In our simulations, we have modeled a cluster of houses in a neighborhood. We used several different numbers of rows and columns in the cluster. The number of rows multiplied by the number of columns gives the number of nodes (houses) in the grid (neighborhood). We developed a C++ program which puts the nodes (houses) randomly on the grid and creates them in the ns-2 simulation format. We also used three extra parameters for the node placement scenario in the proposed scheme. These parameters are v, h and r which represent vertical and horizontal distances between the fixed reference points for consecutive nodes and the amount of randomness used in the placement of nodes. Here, v and h specify how much away the fixed reference points for consecutive nodes are placed from each other along the vertical and horizontal axes, respectively, and the parameter r specifies the maximum distance up to which nodes are randomly placed from their fixed reference points on the grid in both the vertical and horizontal axes (see Figure 3). Nodes are placed by our program as illustrated with Figure 3. Here, using the initial starting position [x, y], our program places the 1st node, which is the node at the 1st row and1st column, randomly within the square area [x-r to x+r, y-r to y+r]. The second node on the same row is placed randomly within the square area [x+h-r to x+h+r, y-r to y+r] and the 3rd node is placed randomly within the square area [x+2.h-r to x+$2.h+r$, y-r to y+r], etc. Likewise, the reference points for consecutive nodes on the same column are placed v meters apart on the vertical axis starting from the position [x, y]. For instance, the 1st node in the 2nd row is placed randomly around its reference point [x, y+v], within the square area [x-r to x+r, y+v-r to y+v+r]. Similarly, the 1st node in the 3rd row is placed randomly around its reference point [x, y+$2.v$], within the square area [x-r to x+r, y+$2.v$-r to y+$2.v+r$], etc.

5. Performance Evaluations

We conducted the performance evaluations of our proposed scheme using Network Simulator-2 (ns-2) [34] with different number of nodes. The channel parameters that are used in our simulations are given in Table 3. These parameters have been experimentally obtained with a set of field tests at 5.9 GHz for different vehicular communication environments, including highway, rural and urban, based on [35]. Here, the authors considered cars moving in the same and opposite directions in urban areas. In addition, they also included the scenario when two communicating cars are stationary while all the other cars are moving.

There are some well-known problems for wireless channels, given as follows [36, 37]:

- Environmental characteristics such as outdoor, indoor, etc.
- Environmental effects including noise, interference, etc.,
- Fluctuations in received signal strengths which is also known as fading,
- Multi-channel effects.

Table 3: Log-Normal Shadowing Parameters

Variable Name	Value
Path loss	1.61
Shadowing deviation	3.4

In addition to these problems, the propagated signal wave may be diffracted, reflected or scattered. All these problems cause a decrease on the received signal strength when the distance increases between transceivers [38, 39]. The following features of radio channels are well-known and have to be considered carefully [40, 41, 42]:

- **Asymmetrical links:** The connectivity from node A to node B may not be same compared to node B to node A,
- **Non-isotropic connectivity:** The connectivity may be different for the same distance from source in all directions,
- **Non-monotonic distance decay:** Nodes which are closer to source may get worse connectivity compared to nodes that are geographically far away from source.

In our simulations, based on the problems and features mentioned above, we have used the log-normal shadowing path loss model as our wireless channel model to get more realistic performance evaluations. Compared to Nakagami and Rayleigh channel models for wireless environments, log-normal shadowing path loss model gives more accurate and realistic results [37].

The signal to noise ratio γ(d) at a distance d from the transmitter in the log normal shadowing path loss model is given as:

$$\gamma(d)_{dB} = P_t - PL(d_0) - 10\eta \log_{10} \frac{d}{d_0} - X_\sigma - P_\eta \tag{1}$$

In equation (1), P_t represents the transmit power in dBm, $PL(d0)$ represents the path loss at a reference distance d_0, η denotes the path loss exponent, X_σ represents a zero-mean Gaussian random variable with standard deviation σ, and P_η denotes the noise power in dBm.

For measuring the performance of our proposed scheme, we made simulations with varying numbers of nodes by changing the v, h and r values which

Table 4: Bus Arrival Times at the Beşiktaş Bahçeşehir University Bus Stop [43]

Bus Number	Arriving Time
29D	10:04:00 AM
43R	10:16:00 AM
25T	10:24:00 AM
58N	10:36:00 AM
63	10:44:00 AM
29C	10:55:00 AM
27E	11:05:00 AM

are defined in section 4. Thus, we achieved different population densities. For each grid size, we used 100 different random seed values for the random placement of the nodes in the grid and ran our simulations 100 times with these seed values. In our performance results, we give the average of the 100 measured values. In order to have more realistic simulations, we used the actual bus arrival times obtained from the Public Bus Transportation Authority of Istanbul (IETT) for the Beşiktaş Bahçeşehir University bus stop, as listed in Table 4. In our simulations, the smart meter data for electricity consumption, load profile of customers and the power quality are transmitted from the houses to the bus every 10 minutes, and when the bus arrives at the bus stop, it transmits all the data collected from the houses in the cluster, for the previous 10 minute time period, to the bus stop.

The simulation parameters which are used in our performance evaluations are listed in Table 5. As shown in the table, constant bit rate (CBR) traffic is utilized. In addition, DSR and AODV are chosen as routing protocol. The speed of the buses are defined random between 45 to 50 km/h.

In our performance evaluations, we investigated the performance of our system, for the transmission of data packets from the smart meters to the buses and from buses to the bus stop, using the following performance metrics:

- **Total End-to-End Delay** is the total time to receive all data on the destination side.
- **Delivery Ratio** is the ratio of the number of successful packets to the total number of transmitted packets.

Table 5: Simulation Parameters

Parameters Name	Value
Network Simulator	NS-2
Channel Model	Log-Normal Shadowing
Number of Columns	2-20
Number of Rows	2-20
Number of Houses	4-400
Number of Bus Stop	1
Number of Buses	7
Avg. Max. Bus Speed	45-50 km / hour
Packet Size	100 Bytes
Simulation Time	3900 Seconds
Traffic Type	CBR
Queue Type	Drop Tail
Routing Protocols	DSR, AODV
Vehicle Movements	Same direction with different speeds

In our mechanism, data generated by a smart meter firstly flows from the house to a bus, and then from the bus to the bus stop. To generate a more realistic report on electricity consumption in the neighborhood for the utility company, it is crucial that data is delivered from all the houses to the bus. Therefore, achieving a high delivery ratio, e.g. as close to 100% as possible, is very important. Similarly, in order to react to changes in the load more quickly and achieve load-balancing in a timely manner, electricity consumption data should be received as fast as possible. Therefore, the end-to-end delay should be as small as possible.

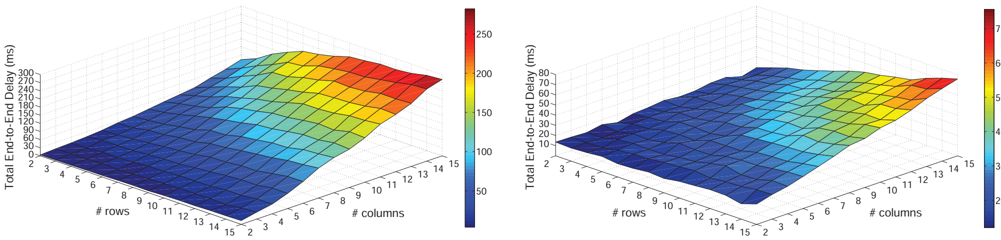
We simulated our proposed smart grid data collection scheme using AODV and DSR, which are two well-known reactive routing protocols, [44] and investigated its performance in detail in terms of total end-to-end delay and delivery ratio. Both AODV and DSR are on demand routing protocols which means they start discovering routes when a demand is initiated by the source node. They both start flooding Route Request (RREQ) packets to find a route from the source to the destination. The main difference between the two routing protocols is that in AODV only one route entry is maintained per destination. On the other hand, in DSR multiple route cache entries are maintained for each destination. However, in order to prevent loops, in

AODV a table-driven routing framework and sequence numbers are used, whereas in DSR source routing is used [45, 46, 47].

5.1. Performance Results for Normal Population Density

In order to investigate the performance of our proposed scheme in a normal population density neighbourhood, we selected the simulation parameters for our node placement scenario as $v = 40$ m, $h = 40$ m and $r = 10$ m. In this scenario, the distance between the reference points for consecutive nodes is 40 m along both the vertical and horizontal axes, and there are a total number of up to 225 houses in the simulated grid.

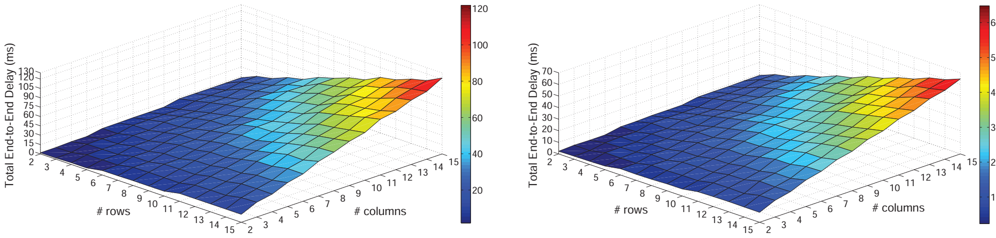
Figure 4 shows the end-to-end delays from houses to a bus, with both the AODV and DSR routing protocols, for our normal population density scenario. As shown in the figure, for both routing protocols, the end-to-end delay increases when the grid size, and hence the number of nodes (houses), increases. For smaller grid sizes, the AODV routing protocol has lower end-to-end delay compared to the DSR routing protocol. On the other hand, for larger grid sizes, DSR has lower end-to-end delay, and even when the numbers of rows and columns both take the maximum value of 15 (which means there are 225 nodes in the cluster), its end-to-end delay is less than 80 milliseconds.



(a) AODV (b) DSR

Figure 4: End-to-end delays from the houses to the bus with the (a) AODV and (b) DSR routing protocols for normal population density

Figure 5 shows the end-to-end delays from the bus to the bus stop with both the AODV and DSR routing protocols for normal population density. As expected, the end-to-end delay increases when the number of nodes increases. An increase in the number of nodes means an increase in the amount of data collected by the bus. As shown in the figure, the AODV routing protocol is more efficient for smaller grid sizes compared to the DSR routing protocol. On the other hand, for larger grid sizes the DSR routing protocol is more efficient and its end-to-end delay is less than 70 milliseconds in all cases.

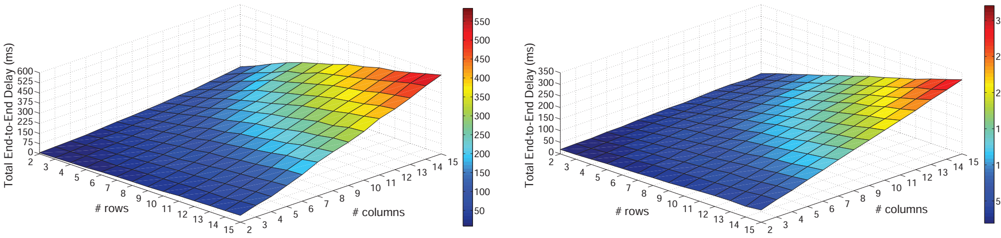


(a) AODV

(b) DSR

Figure 5: End-to-end delays from the bus to the bus stop with the (a) AODV and (b) DSR routing protocols for normal population density

To calculate the total end-to-end delay from the houses to the utility company, we assumed that all bus stops have 1 Mb/sec network connection speed and calculated the delay for transmitting data from a bus stop to the utility using this connection speed. Finally, we added the calculated delay to our end-to-end delay results from houses to the bus stop. Figure 6 shows the total end-to-delays from houses to the utility company, with both the AODV and DSR routing protocols, for normal population density. Note that the results here are the summation of the delay values given in Figures 4 and 5, and the delay due to data transmission from the bus stop to the utility company.



(a) AODV

(b) DSR

Figure 6: Total end-to-end delays from houses to the utility center with the (a) AODV and (b) DSR routing protocols for a normal population density neighbourhood

Figure 7 shows the delivery ratio results with the AODV and DSR routing protocols for smart meter data transmission from the houses, through a bus, to the bus stop in a normal population density neighbourhood. As shown in the figure, the delivery ratio is 100% for all scenarios which means all smart meters successfully transmitted their data to the bus and all collected data on the buses is successfully transmitted to the bus stop.

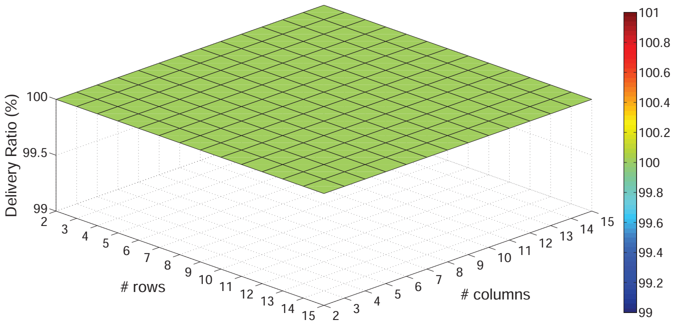


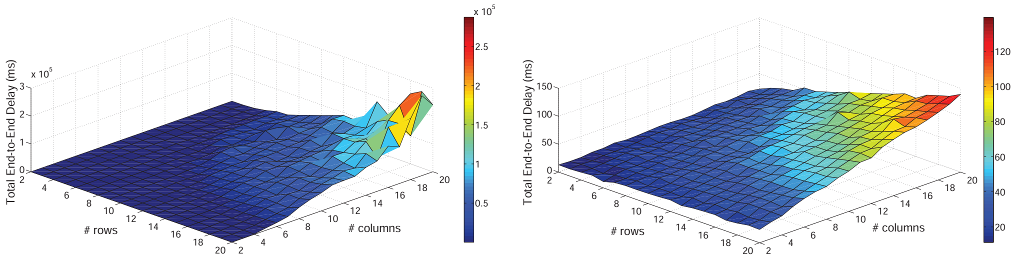
Figure 7: Delivery ratios for smart meter data transmission from houses, through the bus, to the bus stop in a normal population density neighbourhood, using the AODV and DSR routing protocols

5.2. Performance Results for High Population Density

In order to investigate the performance of our proposed scheme in a high population density neighbourhood, we selected the simulation parameters for our node placement scenario as $v = 20$ m, $h = 20$ m and $r = 10$ m. In this scenario, the distance between the reference points for consecutive nodes is 20 m along both the vertical and horizontal axes, and there are a total number of up to 400 houses in the simulated grid.

Figure 8 shows the end-to-end delays for smart meter data transmissions from the houses to the bus using the AODV and DSR routing protocols in a high population density neighbourhood. As shown in the figure, with both routing protocols, the end-to-end delay increases when the grid size (number of houses) increases. Compared to the DSR routing protocol, the AODV routing protocol results in lower end-to-end delays for smaller grid sizes. On the other hand, using the DSR protocol leads to a lower end-to-end delay than the AODV protocol for larger grid sizes.

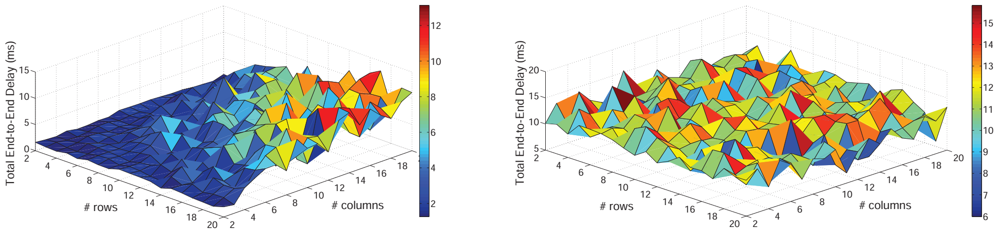
Figure 9 shows the end-to-end delays for smart meter data transmission from the bus to the bus stop, using the AODV and DSR routing protocols,



(a) AODV

(b) DSR

Figure 8: End-to-end delays from the houses to the bus with the (a) AODV and (b) DSR routing protocols for high population density



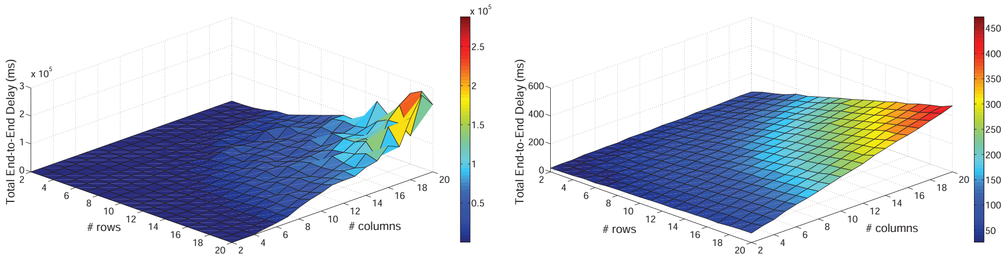
(a) AODV

(b) DSR

Figure 9: End-to-end delays from the bus to the bus stop with the (a) AODV and (b) DSR routing protocols for high population density

in high population density neighbourhoods. As shown in the figure, when the number of nodes increases, the data transmission time increases. We can see that for all grid sizes the AODV routing protocol results in a lower end-to-end delay than the DSR routing protocol.

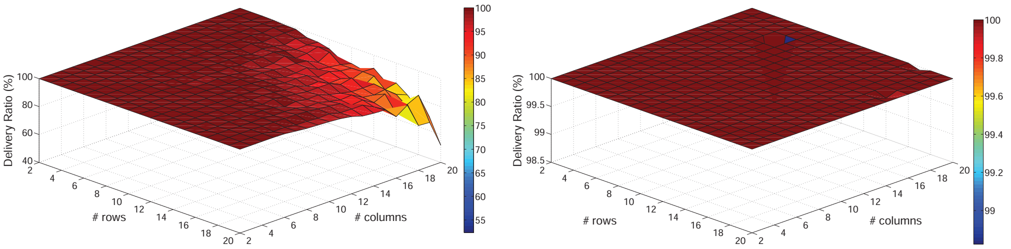
Figure 10 shows the total end-to-delays from houses to the utility center in high population density neighbourhoods, for both the AODV and DSR routing protocols. These delay values are the summation of the delay values given in Figures 8 and 9, and the delay due to data transmission from the bus stop to the utility company. Although, the AODV routing protocol results in lower end-to-end delays than the DSR routing protocol for smaller grid sizes, for larger grid sizes DSR results in lower end-to-end delay values than AODV. Even when the numbers of rows and columns take the maximum value of 20 (which means there are 400 houses in the grid), the total end-to-end delay is less than 500 milliseconds with DSR. Whereas, with AODV, in



(a) AODV (b) DSR

Figure 10: Total end-to-end delays from the houses to utility with the (a) AODV and (b) DSR routing protocols for high population density

the same scenario with 400 houses in the grid, the total end-to-end delay has the dramatically higher value of more than 287 seconds.



(a) AODV (b) DSR

Figure 11: Delivery ratios for smart meter data transmission from houses to the bus in high population density neighbourhoods with (a) AODV and (b) DSR routing protocols

Figure 11 and 12 show the delivery ratios for smart meter data transmission from the houses to the bus and from the bus to the bus stop, respectively, in high population density neighbourhoods, using the AODV and DSR routing protocols. As shown in the figure 11, with the AODV routing protocol, the delivery ratio for data transmission from houses to bus decreases when the number of nodes increases. The delivery ratio decreases down to 52% for AODV. For the same data transmission scenario, the DSR routing protocol achieves almost 100% delivery ratio, i.e. the delivery ratio is always higher than 98%. As shown in Figure 12, with both AODV and DSR, the delivery ratio is 100% for smart meter data transmissions from the bus to the bus stop.

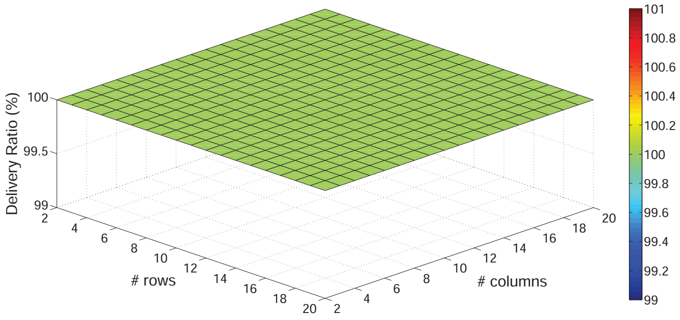


Figure 12: Delivery ratios for smart meter data transmission from the bus to the bus stop in a high population density neighbourhood with (a) AODV and (b) DSR routing protocols

5.3. Performance Results for Hop-by-Hop Communication in a Low Population Density Neighbourhood

For neighbourhoods where some houses are located farther than 1000 m away from bus roads, we explored the applicability of our scheme using multi-hop communication between a houses and a bus. In urban areas, houses are typically covered by streets with running public transportation lines. However, houses in rural areas, or houses in urban areas which are more than 1000 m away from a bus line, can still transmit their smart meter data to the bus through intermediary houses using an extended version of our scheme which allows hop-by-hop communication. In this scenario, the last house in the hop-by-hop communication should be within 1000 m distance from the bus line. In this study, we conducted simulations for a 2-hop communication scenario where a house communicates its smart meter data to the bus through another intermediary house that is within 1000 m proximity from the bus road. In our node placement scenario, we have two consecutive neighbourhoods, each in the shape of a 13x13 grid (with 169 houses), where one of the neighbourhoods is placed completely within 1000 m from the bus line and the other one is located outside the coverage range of the bus line. Here, the houses in the distant neighbourhood communicate with the bus through an intermediary house located in the consecutive neighbourhood that is within the coverage area of a bus line. The simulation parameters for our node placement scenario are defined as $v = 80$ m, $h = 80$ m, $r = 40$ m. In this situation, the distance between nodes are 80 m for both the vertical and horizontal axes.

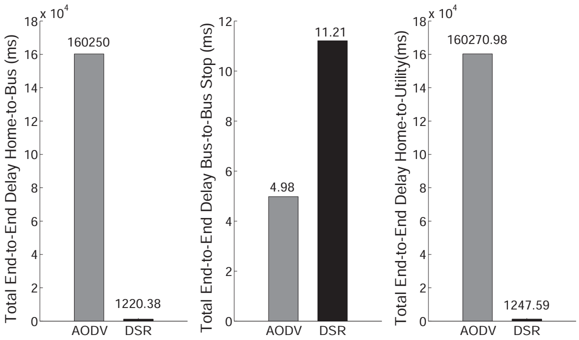


Figure 13: Total end-to-end delays with the AODV and DSR routing protocols for the hop-by-hop communication scenario

Figure 13 and 14 show the total end-to-end delays and the delivery ratios for AODV and DSR routing protocols, respectively, for 2-hop communication in a low population density neighbourhood. As shown in Figure 13, AODV has lower delay than DSR for smart meter data transmission from bus to bus stop. On the other hand, for data transmission from houses to the bus, DSR has lower delay than AODV. In terms of delivery ratio, as shown in the Figure 14, DSR performs better than AODV for smart meter data transmission from houses to buses. With both AODV and DSR, the delivery ratio is 100% for smart meter data transmission from the bus to the bus stop.

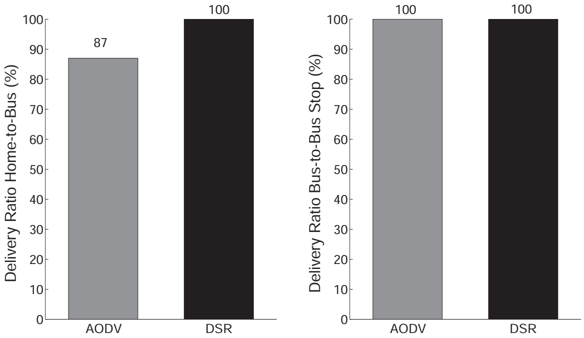


Figure 14: Delivery ratios with the AODV and DSR routing protocols for the hop-by-hop communication scenario

6. Conclusion

Wireless communication technologies have been used widely in many applications, e.g. environmental applications, health applications, home applications, monitoring applications, smart grid environments, surveillance applications and vehicular communications. In this study, we proposed a solution to the data collection problem in smart grids using the wireless communication technology and by merging the smart grid AMI technology with vehicular Ad-Hoc networks. We proposed a data collection mechanism that extends the communication range of smart meters by up to 1000m by adapting the IEEE 802.11p communication protocol. With this new communication model, data generated by smart meters can be transmitted to the utility company via public transportation buses. In our proposed mechanism, smart meters transmit their data to a public transportation bus and then the bus transmits the data to the bus stop with a network connection. The bus stop then transmits the smart meter data to the utility company. We have evaluated the performance of the proposed data collection mechanism in terms of end-to-end delay and delivery ratio with two different routing protocols, namely the AODV and DSR protocols, for normal density, high density and hop-by-hop communication scenarios. Importantly, the channel parameters used in the simulations were obtained from a set of field tests at 5.9 GHz in different environments. Our performance evaluations show that the proposed data collection mechanism achieves high delivery ratio and low end-to-end delay when the DSR routing protocol is used.

Although, our proposed scheme has advantages, there are also some drawbacks to it. For example, when a smart meter wants to transmit its data to a bus, there may be no buses passing by its coverage area for a period of time and the data transmissions may be delayed in this case. In addition, the receiver on the bus passing by, or at the bus stop, may be out of order which would also result in delays. In these cases, smart meters can still transmit their data to a later bus which will transmit the collected data to one of the many bus stops on the same bus line.

We identify future research directions as follows:

- The privacy and security issues of the proposed scheme may be studied.
- The situation when there are no bus lines within the communication range of a smart meter, and the use of the extended scheme with hop-by-hop communication, may be further studied.

- The influence of different packet sizes on the efficieny of the proposed mechanism may be studied.

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Highlights

- The first study which uses public transportation for collecting data from SM.
- Our study only needs the IEEE 802.11p communication protocol capability on WAMR.
- Unlike other VANET studies, our study uses both I2V & V2I communication.