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Research Article

Collecting smart meter data via public transportation buses

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Abstract: With advances in technology, wireless sensor networks (WSNs) have found new applications and their popularity has increased dramatically. In several applications, WSNs have the potential to replace wired data communication systems, e.g. in vehicular *ad hoc* networks (VANETs) they are the natural option for data communication. WSNs are also proposed for data communication in the emerging smart grid. In this study, the authors merge these two application domains, i.e. VANET and smart grids, and propose a novel solution for effective smart grid data communication. The authors' proposed scheme achieves the task of collecting data from smart meters by utilising VANETs. Using network simulator-2 and with different routing protocols, the authors have performed simulations and shown the efficacy of their scheme in terms of average end-to-end delay and delivery ratio.

1 Introduction

Recently, with new advances, wireless sensor networks (WSNs) have started replacing wired systems in several settings, including military, environmental monitoring, health-related and home applications, smart grid environments and vehicular communication [1]. WSNs have been deployed widely due to their low-cost and collaborative nature.

The smart grid is the evolving and modernised version of the existing traditional electricity grid. The main functionality of the smart grid is its two-way communication capability, which facilitates self-healing through real-time monitoring and timely reaction to incidents. Furthermore, by recording consumer electricity consumption data frequently and transmitting it to the utility company, it leads to cost-efficiency in electricity production and distribution [2, 3]. By using the advanced metering infrastructure and smart meters, two-way data communication can be achieved between utility companies and consumers. Smart meters are electronic devices that collect and record data on electricity consumption, system status and diagnostic issues. By providing information about electricity usage 24/7, smart meters enable utility companies to have optional pricing programs and achieve real-time system analysis [2, 4].

The recently emerging vehicular *ad hoc* networks (VANET) are a special form of mobile a*d hoc* networks. In a VANET, there are basically two types of communication: vehicle-to-vehicle (V2V) communication, which is the communication between vehicles, and vehicle-to-infrastructure (V2I) communication, which is the communication between vehicles and road-side devices. Dedicated short range communication and IEEE 802.11p communication protocols are used in both communication types. In IEEE 802.11p, the communication range has been expanded to 1000 m and the data rate has been expanded from 6 to 27 Mbps. The common applications of V2V and V2I communication are forward collision/accident warning, blind spot warning, lane change warning, do-not-pass warning at the intersection, alerts on weather-related information and emergency vehicle warning [5–7].

In this work, we explore the existing mechanisms for collecting data from smart meters and offer a new mechanism based on vehicular networks. Our solution enables collecting smart meter data using public transportation buses by extending the communication capability of smart meters to IEEE 802.11p. Since IEEE 802.11p allows communication in ranges up to 1000 m, smart meters within 1000 m of a public bus stop can transmit their data to the bus stop, and buses passing by the bus stop can receive the data and then transmit it to a central database via road side units.

Main Contributions:

(i) There exists no published work on collecting smart meter data by using buses or other public transportation vehicles; this is the first such scheme to the best of our knowledge.
(ii) The proposed system only needs smart meters with IEEE 802.11p communication capability and transceivers on bus stops. We propose the use of IEEE 802.11p for smart grid data collection for the first time in literature.
(iii) Our proposed scheme is novel in that, unlike many existing vehicular communication schemes that utilise V2I communication, our scheme uses infrastructure-to-vehicle communication. In our study, the data in vehicular communication flows from infrastructure (bus stop) to vehicle. However, the proposed scheme would also allow reverse data flow from a bus to a smart meter through a bus stop, e.g. when the utility company wants to transmit an alert message to its customers such as a message containing a reconfiguration file. Thus, the utility control centre can communicate with a smart meter within minutes through a bus passing by the bus stop.
(iv) For comprehensive performance results, we conducted simulations with various densities/distributions of houses and different routing protocols.
(v) We also considered the case when smart meters (houses) are located farther than 1000 m from the bus stop, and conducted simulations assuming data communication in a hop-by-hop fashion. In this scenario, we assumed distant smart meters transmit their data through intermediary houses which relay their smart meter data to the bus stop.

2 Related work

The main problem in the classical data collecting model from meters, in the traditional electric grid, is that it does not provide two way communications. Due to this problem, utilities cannot learn actual demand on peak and non-peak hours. In the classical model, utilities get their employees to read meters by sending them to

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houses. In this case, there are limited hours to read meters, and if there is no one in a building, since employees cannot enter the building, they cannot read meters.

In the literature, there are numerous studies on automatic meter reading (AMR) systems. With recent advances in wireless technology, there are studies that expand AMR systems to wireless AMR (WAMR). With their two way communication capability, AMR systems reduce meter reading expenses of utilities. More importantly, they help utilities get timely individual electricity consumption data from their customers, which helps prevent illegal electricity usage. AMR systems also make it possible to access and control meters even when there is no one in the house. There are four types of AMR systems, given as follows [8]:

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

In [4], the authors offered using the Global System for Mobile Communications (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 using GSM and at the end of each month, the utility suggested method would facilitate the generation of bills and send them to customers via SMS or e-mail.

In [8], the authors proposed a cost effective novel approach for AMR systems in rural areas. As an alternative to hiring people for meter reading, their approach offers using unmanned vehicles with global positioning system capability to read meters. They used the IEEE 802.15.4 communication protocol for their AMR system. They also made 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 [9], the authors designed and implemented a WAMR system by adding wireless modules to existing meters. They used the ZigBee [10] communication protocol with a short range and low power consumption. In their system, wireless modules are connected to meters through RS485 buses. These wireless data collecting modules transmit their data to a sink node either individually or through multi-hop communication. Moreover, on the sink node, the received data is wirelessly transmitted to the server node via an RS232 bus.

In [11], the authors gave a comprehensive review of the existing AMR technologies and discussed their challenges. Furthermore, they gave information on future communication technologies for smart grids, e.g. 3G, DLSM/COSEM and Internet Protocol-based session initiation protocol (SIP).

Although all the mentioned studies made important amendments on existing AMR systems or proposed alternative mechanisms for collecting data from meters, there is no published study about collecting data from meters using public buses or other public transportation vehicles. Almost all bus stops in Istanbul are smart bus stops with embedded computers containing Wi-Fi and other wireless communication modules. In 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 the nearest smart bus stop, and the buses passing by the bus stop may get the data and transmit it to a central database owned by the utility company. The proposed scheme would be cost effective and provide a novel solution for transmitting consumer data to the utility company in a timely manner.

3 Proposed scheme

In our proposed scheme shown in Fig. 1, data flows from houses, which have WAMR with 802.11p capability, to a bus stop, and then collected data on the bus stop is transmitted to a bus which drives by on its scheduled time. Upon receiving the collected data, the bus transmits it to the utility company using its on-board wide-band communication capability. Although we focus on the flow of smart meter data from smart meters to buses in this study, the proposed scheme would allow reverse data flow as well. For instance, if the utility control centre wants to transmit an alert message to its customers, e.g. a new electricity unit price or a new campaign, or if it wants to send a message containing a reconfiguration file, a bus can download this message to the nearby bus stop within minutes, and finally the bus stop can transmit the message to the corresponding house. In the same way, regular updates to smart meters could be realised during specific times of the day.

Istanbul has a wide and dense network of bus stops and the distance between two bus stops in a typical urban neighbourhood is around 500 m, as shown in Fig. 2. Note in Fig. 2*b* the three neighbouring bus stops in the central Besiktas neighbourhood, located only 465.1 and 402.8 m apart. Hence, in urban neighbourhoods of Istanbul, smart meters having a WAMR system with 802.11p capability can easily communicate with a nearby bus stop. With our proposed scheme, houses outside the direct communication range of a bus stop, i.e. farther than 1000 m from a bus stop, e.g. in rural areas far from city centre, can still communicate with a bus stop through an intermediary house, or through multiple intermediary houses, in a hop-by-hop fashion, as shown in Fig. 1*b*.

4 Performance evaluations

In this section, the performance of the proposed data collecting mechanism is investigated. We conducted our performance evaluations using the ns-2 [12] simulator with different numbers of sensor nodes. We used the experimentally determined log-normal channel parameters for different smart grid environments based on [13].

Wireless channel suffers from multi-channel effects, fluctuations in received signal strengths (fading), environmental characteristics such as outdoor, indoor, and so on and environmental effects such as noise [14, 15]. Also, there may be diffraction, scattering or reflection on the propagated signal wave. All these factors lead to decreased signal strength at the receiver as the distance between the source and destination increases [16, 17]. The following features of radio channels cause the fading phenomenon [18–20]:

- *Asymmetrical links:* Connectivity between nodes may be different;
- *Non-isotropic connectivity:* Connectivity is not required to be the same in all directions;
- *Non-monotic distance decay:* Nodes far away from the source may get better connectivity compared with nodes that are geographically closer.

Therefore, a more general wireless channel model, based on empirical measurements, is required for more realistic performance evaluations.

We have used the log-normal shadowing path loss model as the wireless channel model in our simulations, because this model is known to give more accurate results compared with Nakagami and Rayleigh models for wireless environments [14]. In the log normal shadowing path loss model, the signal to noise ratio $\gamma(d)$ at a distance d from the transmitter is given in as

$$\gamma(d)_{d\beta} = P_t - PL(d_0) - 10_\eta \log_{10}\left(\frac{d}{d_0}\right) - X_\sigma - P_\eta. \quad (1)$$

In (1), P_t, $PL(d_0)$, η, X_σ and P_η denote the transmit power in dBm, the path loss at a reference distance d_0, the path loss exponent, a zero-mean Gaussian random variable with standard deviation σ and the noise power in dBm, respectively. The log-normal channel parameters have been obtained with a set of field tests at 5.9 GHz, on highway, rural and urban environments. In our simulations, we used 1.61 as the path loss parameter and 3.4 as the shadowing deviation.

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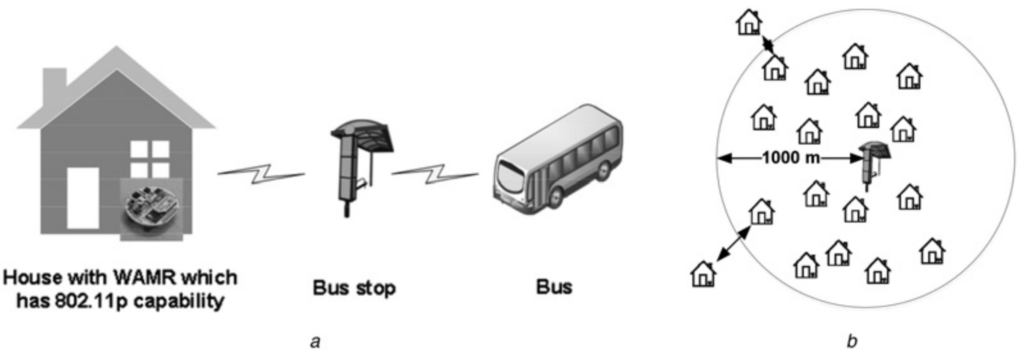

Fig. 1 *Proposed and extended*

a Data collecting scheme
b Scheme allowing hop-by-hop communication

In our simulations, we have modelled a cluster of houses in a neighbourhood. For each simulation, we specified the number of rows and columns, which represent the number of horizontal and vertical lines along which houses are randomly aligned. Here, the number of rows multiplied with the number of columns in the cluster gives the number of nodes/houses (see the exemplary clusters in Fig. 3). Although we consider a grid structure, i.e. rows and columns of houses, the houses in the cluster are placed randomly to emulate houses in a neighbourhood. In our simulations, the starting point of the first node is fixed and the rest of the houses are randomly placed on the grid. We developed a C++ program to create the nodes (houses) in the ns-2 format and place them randomly on a grid. Our C++ program takes as input some simulation parameters such as the numbers of rows and columns in the grid and the initial starting position $[x, y]$ of the node in the first row of the first column. Further simulation parameters are v and h, which denote the vertical and horizontal distances, respectively, between the starting points of consecutive nodes, and r which specifies up to how far away a node can be randomly placed from its starting position both in the horizontal and vertical axes. Then, nodes are randomly placed according to the following rule. Using the initial starting position $[x, y]$, our program places the first node (the node at the first row and first column) randomly within the square area $[x-r$ to $x+r$, $y-r$ to $y+r]$. The starting points for the first node in the second row is placed randomly around $[x, y+v]$, within the square area $[x-r$ to $x+r$, $y+v-r$ to $y+v+r]$. Similarly, the first node in the third row is placed randomly around $[x, y+2.v]$, within the square area $[x-r$ to $x+r$, $y+2.v-r$ to $y+2.v+r]$, and so on. Likewise, the starting points for consecutive nodes on the same row are at a distance of h from each other. For instance, if the first node on a row is placed randomly within the square area $[x-r$ to $x+r$, $y-r$ to $y+r]$, the second one is placed randomly within the square area $[x+h-r$ to $x+h+r$, $y-r$ to $y+r]$, the third one placed randomly within the square area $[x+2.h-r$ to $x+2.h+r$, $y-r$ to $y+r]$, and so on. For each grid size, we used 100 different random seed values for the random placement of the nodes on the grid and ran our simulations with these seed values. An exemplary 8×8 cluster, a bus passing by and the bus stop are shown in Fig. 3*a*. In our performance results, we give the average of all the 100 measured values. During each simulation, which lasts for 3900s, seven buses approach the bus stop according to the schedule given in Table 1. In our performance results, we give the average of all the seven measured values. In order to make our simulations more realistic, we used the actual bus arrival times obtained from the Public Bus Transportation Authority of Istanbul (IETT) for the Besiktas Bahcesehir University bus stop, as listed in Table 1.

In our simulations, the electricity consumption data is transmitted from the houses to the bus stop every 10 min, and when a bus arrives at the bus stop, it receives from the bus stop the collected electricity consumption data of all the houses in the cluster for the last 10 min time period. We utilised constant bit rate (CBR) traffic in our simulations. As the routing protocol, we tried the Dynamic Source Routing (DSR) and ad-hoc on-demand distance vector (AODV) routing protocols, since they are the most commonly used routing protocols for VANET studies. In our simulations, the buses move

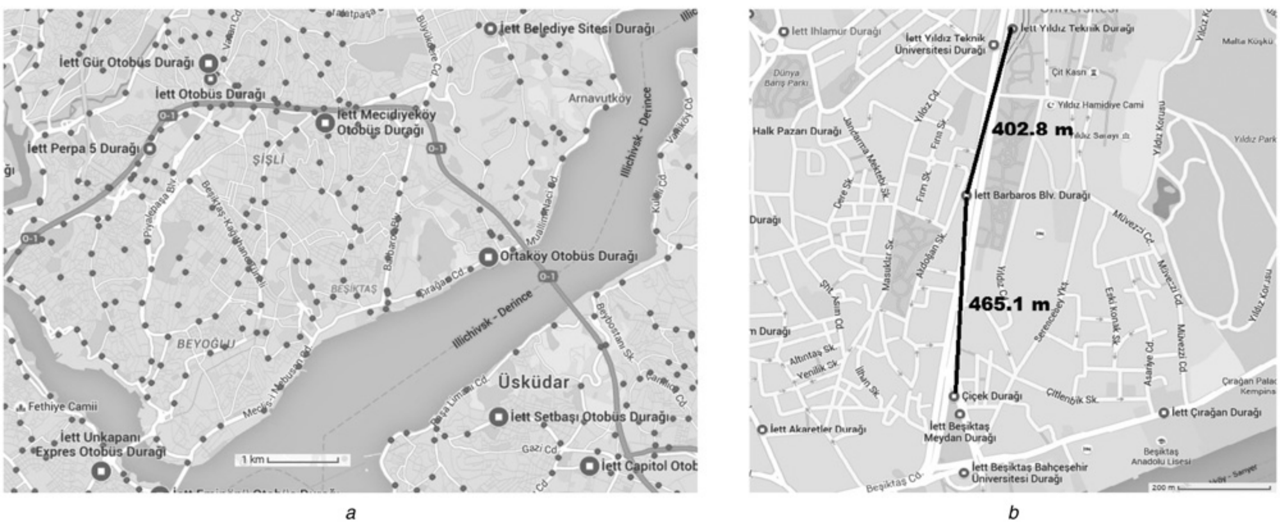

Fig. 2 *Wide and dense network of Istanbul bus stop*

a Map of Istanbul bus stops
b Distance between neighbouring bus stops

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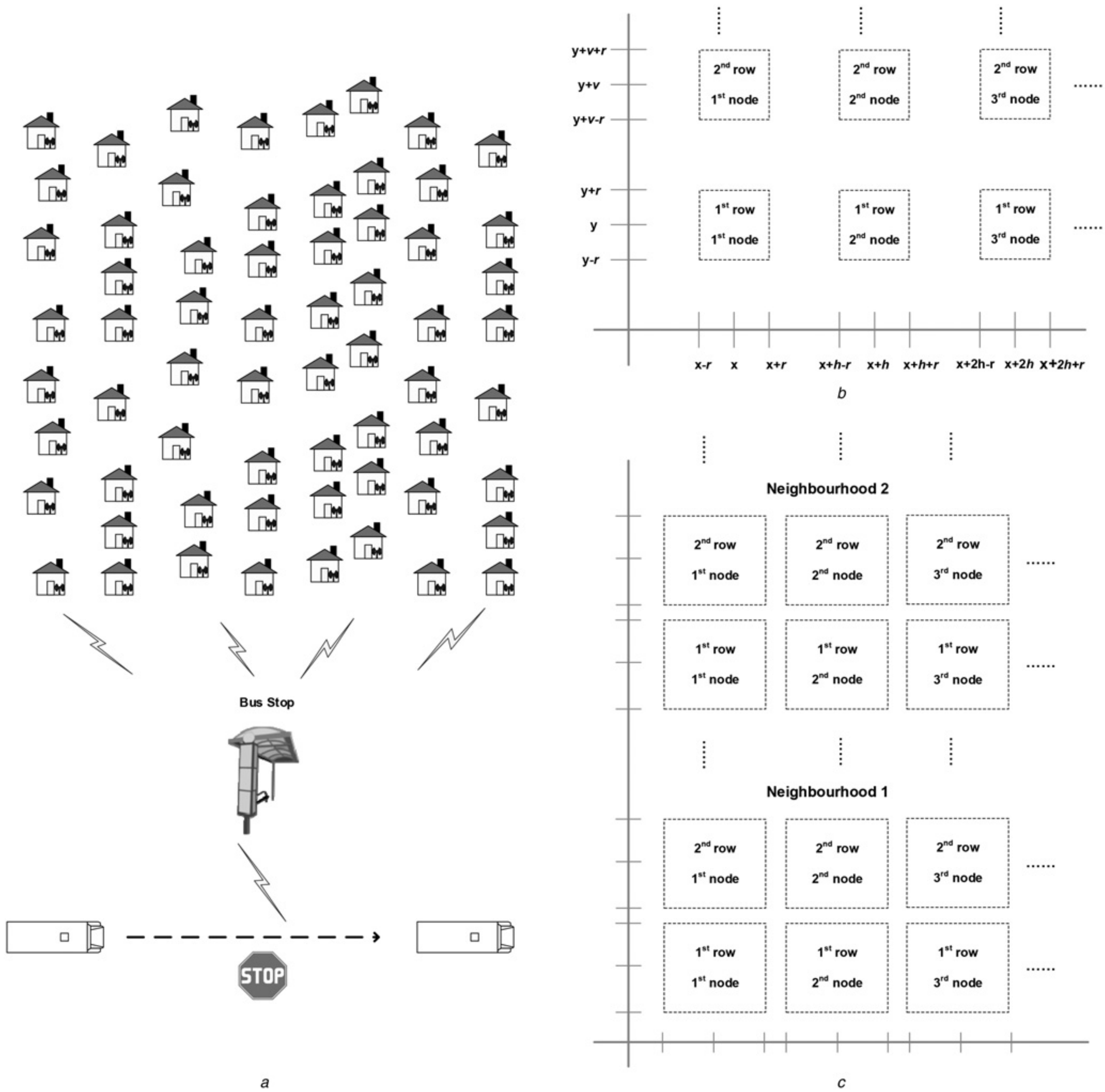

Fig. 3 *Performance evaluations*

a 8 × 8 Cluster of nodes
b Node placement scenario
c Node placement scenario for hop-by-hop communication in a low population density neighbourhood

Table 1 Bus arrival times for the Besiktas Bahcesehir University bus stop [21]

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

Table 2 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 stops	1
number of busses	7
average maximum bus speed	45–55
packet size	100 bytes
simulation time	3900 s
traffic type	CBR
queue type	drop tail
routing protocol	DSR, AODV
vehicle movements	same direction with different speed

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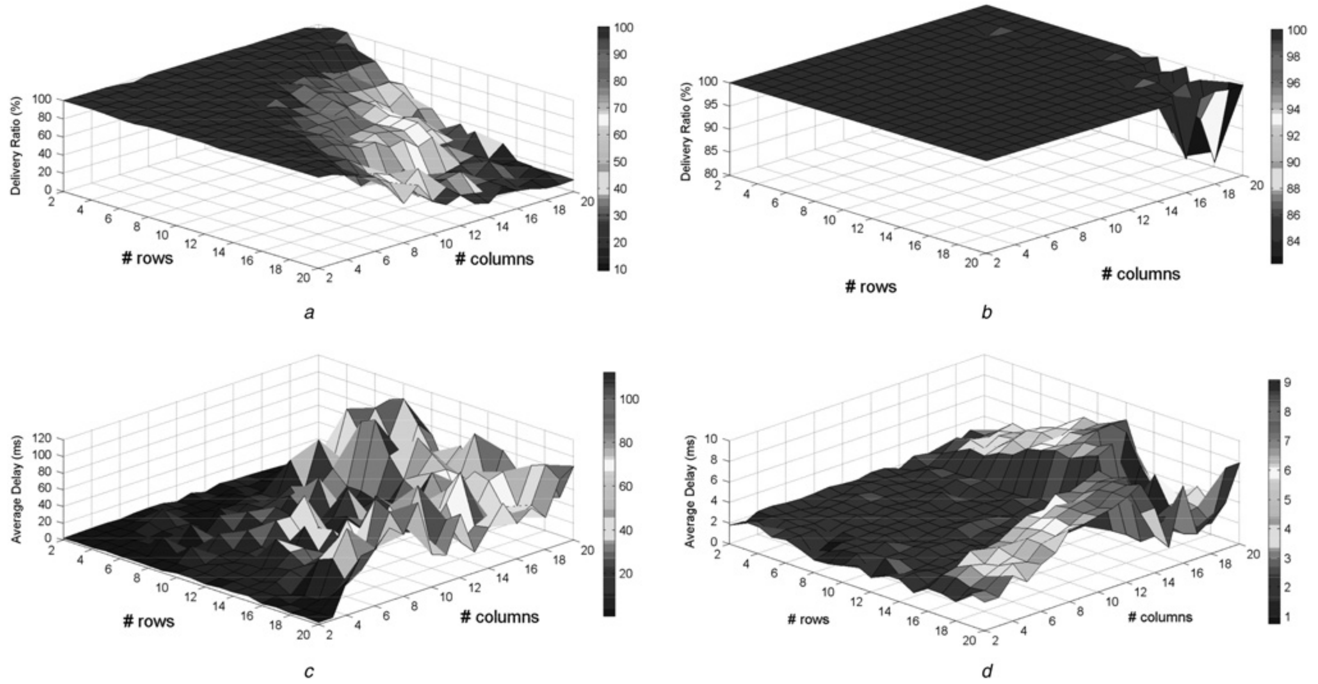

Fig. 4 *Simulation results in a normal population density neighbourhood for*
a Delivery ratio with AODV
b Delivery ratio with DSR
c End-to-end delay with AODV
d End-to-end delay with DSR

in the same direction at a random speed of 45–55 km/h. All the parameters used in our performance evaluations are listed in Table 2.

We investigated the performance of the proposed scheme for the transmission of data packets from smart meters at houses, through the bus stop, to buses, all with IEEE 802.11p capability, using the following performance metrics:

- *End-to-end delay:* Required time to receive all data packets at destination.
- *Delivery ratio:* Ratio of the number of successfully transmitted packets to the total number of transmitted packets.

Successful transmission of consumer electricity consumption data from all houses to the bus stop is crucial in our mechanism. If data from some houses is lost during transmission, using the collected data the utility company may not produce a realistic data consumption report, which would decrease the efficiency of load balancing operations. Therefore, achieving a high delivery ratio is important. Similarly, the utility company needs to obtain the electricity consumption data in a timely manner to react to changes in load more quickly, which necessitates the data flow from the houses, through the bus stop, to the buses to be as fast as possible. Therefore, achieving a minimal end-to-end delay is desired.

For the proposed system, we compared the performance of the AODV and DSR routing protocols in terms of the delivery ratio and end-to-end delay performance metrics. Both AODV and DSR start discovering routes when a demand is initiated by the source node. Both of them broadcast route request packets to find a path from the source to the destination. The main difference between AODV and DSR is that in DSR multiple route cache entries are maintained for each destination, whereas in AODV one route entry is maintained per destination. Furthermore in DSR, source routing is used whereas in AODV a table-driven routing framework and sequence numbers are used to prevent loops [22–24].

For testing the performance of the proposed scheme for varying node population densities, we performed simulations with varying numbers of nodes, representing neighbourhoods with different population densities. We achieved this by changing the simulation parameters v, h and r. We conducted simulations for neighbourhoods with up to 400 blocks of houses, with the population densities of 676, 1326 and 169 houses/km^2, for normal, high and low population density neighbourhoods, respectively. The proposed data collecting mechanism is ideally offered for urban neighbourhoods where consecutive bus stops are <2 km apart and houses are <1 km away from the nearest bus stop. This will potentially yield a 100% coverage using the IEEE802.11p protocol. We used a simulation space of size 800 × 800 m in the maximum to ensure all nodes in the simulation are within 1 km from the bus stop. As noted in Fig. 2, the average distance between consecutive bus stops in Istanbul is around 500 m in urban neighbourhoods, and hence an 800 × 800 m simulation space is reasonable. For low, normal and high population density neighbourhoods, we set the distances between consecutive nodes to be around 40–80 m by setting the simulation parameters v, h and r accordingly. Hence, along a distance of 800 m, there can be up to 800 m/40 m = 20 houses. We considered row and column sizes of up to 20 in our simulations, resulting in a total number of up to 400 houses.

For the scenario when some houses are farther than 1000 m from the nearest bus stop, we also investigated through simulations the performance of a hop-by-hop data communication scheme. In this case, the smart meter data for the distant house is sent to the bus stop through an intermediary house in a hop-by-hop fashion.

4.1 Performance results for neighbourhoods with normal population density

For normal population density neighbourhoods, we used the simulation parameters $v = 40$ m, $h = 40$ m and $r = 10$ m in our node placement scenario, which results in a population density of 676 houses/km^2. In this case, the starting points for consecutive nodes are placed 40 m apart on both the horizontal and vertical axes. In Fig. 4, we give the simulation results for delivery ratio and end-to-end delay with the AODV and DSR routing protocols.

With AODV, for lower numbers of nodes the delivery ratios are higher, and all delivery ratios are between 98.00 and 100%. As the

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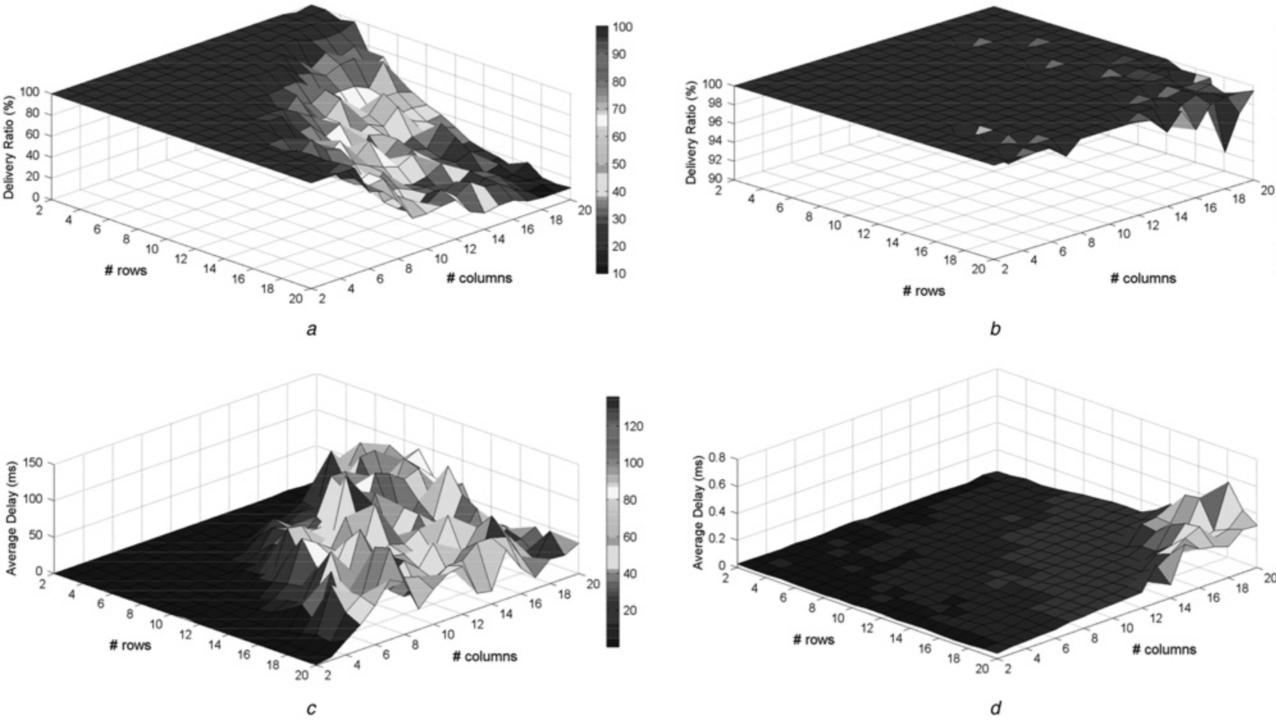

Fig. 5 *Simulation results in a high population density neighbourhood for*

a Delivery ratio with AODV
b Delivery ratio with DSR
c End-to-end delay with AODV
d End-to-end delay with DSR

numbers of rows and columns increase, delivery ratio decreases. Especially, when both the number of rows and the number of columns are higher than 15, the delivery ratio goes under 40%. The minimum and average delivery ratios with AODV are 9.39% (for the grid 20 × 18) and 75.74%, respectively. With DSR, for most cases the delivery ratio is between 96.00 and 100%. It starts decreasing when the number of rows and columns are both higher than 18, however it stays between 82.28 and 96.00%. The

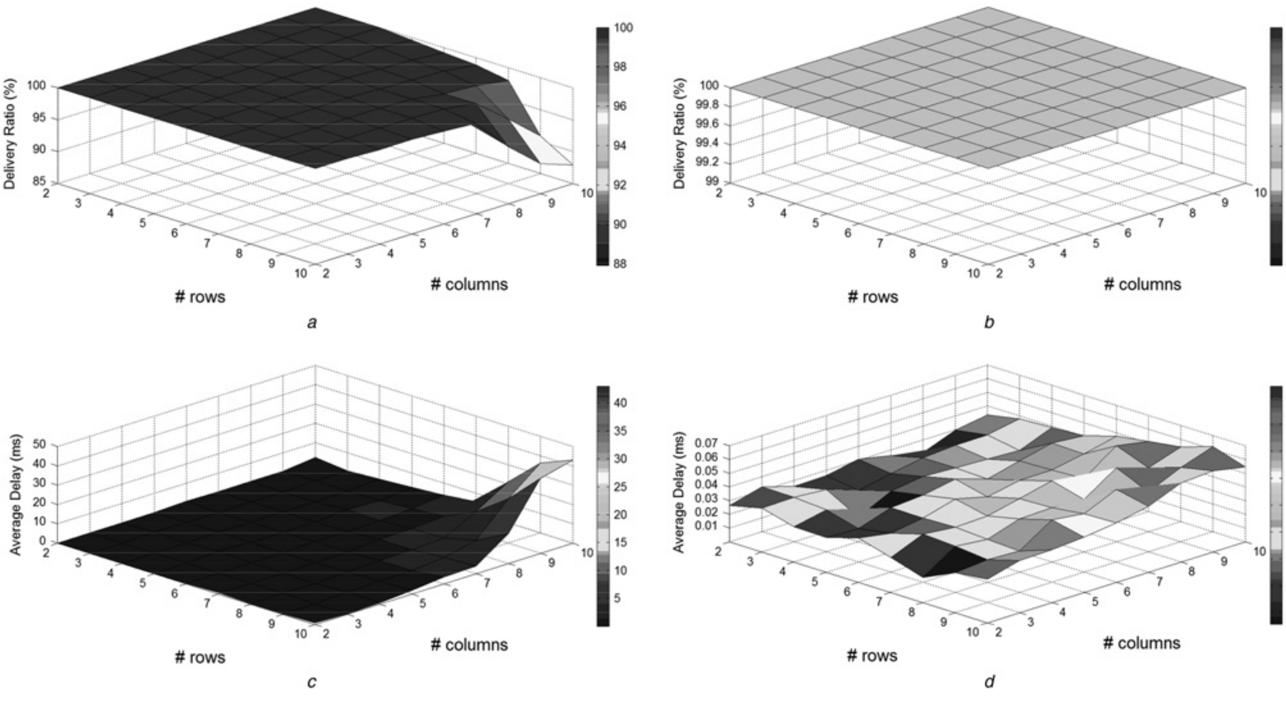

Fig. 6 *Simulation results in a low population density neighbourhood for*

a Delivery ratio with AODV
b Delivery ratio with DSR
c End-to-end delay with AODV
d End-to-end delay with DSR

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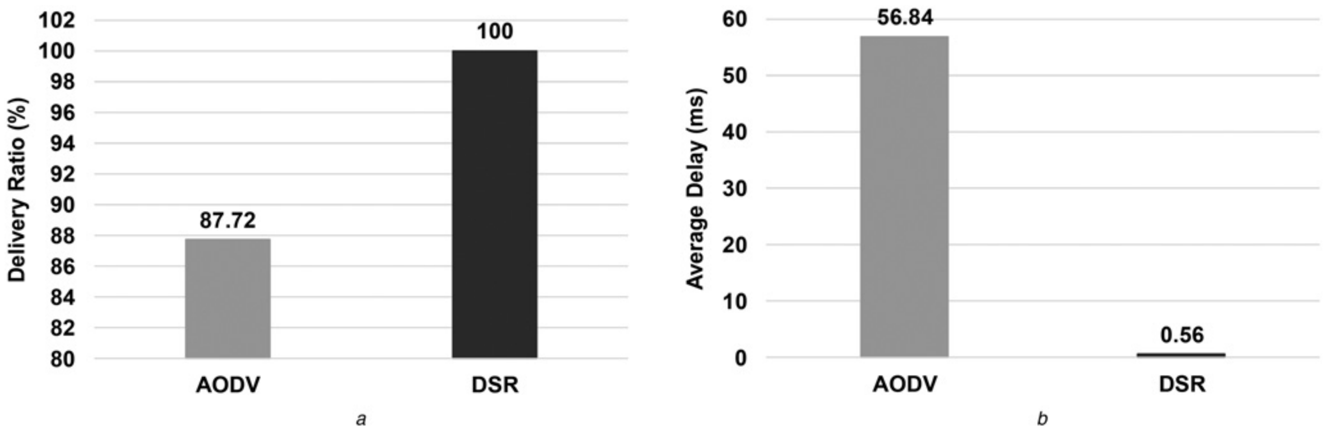

Fig. 7 *Hop-by-hop communication with the AODV and DSR routing protocols in low population density neighbourhoods for*

a Delivery Ratio results
b Average end-to-end delay results

minimum delivery ratio of 82.28% occurs for the 17 × 19 grid and the average delivery ratio for all the simulated grid sizes is 99.61%. We can see that for larger grid sizes, i.e. higher numbers of nodes, the delivery ratios are dramatically low with AODV, and in general, the delivery ratios are much better with DSR.

As seen in Fig. 4, with both routing protocols, when the number of nodes increases, the end-to-end delay also increases. The delay values are higher with AODV, compared with DSR. This may be due to the fact that the delay increases when the routing table entries in AODV expire. Note that a routing table entry expires if it has not been used recently. All in all, DSR gives better results with the maximum delay of only 0.56 ms, compared with AODV with the significantly larger maximum delay of 135.31 ms. The average delay values are 31.68 and 0.08 ms with AODV and DSR, respectively. Note that in our proposed method most of the nodes are static and the only mobile nodes are the buses. Since the number of mobile nodes in our network is small, DSR gives better results. Furthermore, since AODV uses route expiry, packet drops may occur in this protocol when a new route is discovered, resulting in increased packet transmission times.

4.2 Performance results for neighbourhoods with high population density

We used the simulation parameters $v = 40$ m, $h = 20$ m and $r = 10$ m in our node placement scenario for a high population density neighbourhood, which results in a population density of 1326 houses/km^2. In this case, the starting points for consecutive nodes are placed 20 m apart on the horizontal axis for nodes on the same row and 40 m apart on the vertical axis for nodes on the same column. Note here that we allowed the spacing between consecutive rows to be larger than the spacing between consecutive columns to allow for interior parallel roads between rows of houses.

We give the simulation results for delivery ratio and end-to-end delay, with both the AODV and DSR routing protocols, in Fig. 5. The average delivery ratio for all the number of nodes is 73.47% for AODV and 99.88% for DSR. With AODV, when both the number of rows and columns are higher than 16, the delivery ratio drops under 35% and the minimum delivery ratio is 9.95% (for the 20 × 19 grid). With DSR, the minimum delivery ratio of 91.99% occurs for the 18 × 20 grid. The maximum observed delay values are 111.94 and 9.07 ms, and the average observed delay values are 30.01 and 3.60 ms, with AODV and DSR, respectively. In terms of delivery ratio and delay, while AODV is suitable for only smaller grids with lower number of nodes, DSR can be used for all grid sizes.

4.3 Performance results for neighbourhoods with low population density

For low population density neighbourhoods, we used the simulation parameters $v = 80$ m, $h = 80$ m and $r = 40$ m in our node placement

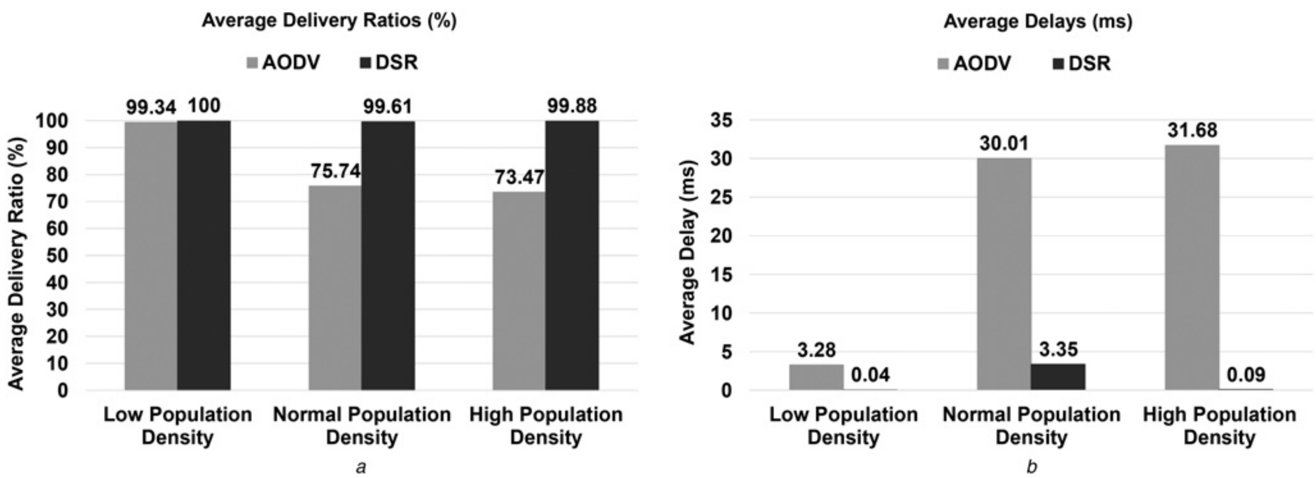

Fig. 8 *Simulation results for*

a Delivery ratio
b End-to-end delay

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scenario, which results in a population density of 169 houses/km^2. In this case, the starting points for consecutive nodes are placed 80 m apart both on the horizontal and vertical axes for nodes placed on the same row and column, respectively.

The simulation results for delivery ratio, with both the AODV and DSR routing protocols, are given in Fig. 6. As seen in the figure, with AODV, for lower number of nodes, the delivery ratio is 100%, and for the number of nodes between 50 and 80, the delivery ratio is between 98.00 and 100%. As the number of nodes increases above 80, the delivery ratio sharply decreases. Particularly, for the number of nodes higher than 90, the delivery ratio decreases down to 90%. Although the minimum delivery ratio is 87.95% (for the grid 10×10), the average delivery ratio for all grid sizes is 99.34%. With DSR, for all number of rows and columns, the delivery ratio is 100%. In terms of delivery ratio, the proposed mechanism gives good results with both AODV and DSR for small grid sizes, however DSR is more desirable for larger grid sizes.

In Figs. 6*c* and *d*, the simulation results with both AODV and DSR are given for end-to-end delay. With both protocols, when the number of nodes increases, the delay also increases. For number of nodes higher than 80, the delay exceeds 20 ms and the maximum delay is 43.01 ms (for the 10×10 grid and with AODV). The maximum delay value with DSR is only 0.06 ms. The average delay values are 3.28 and 0.037 ms with AODV and DSR, respectively.

4.4 Performance results for hop-by-hop communication in low population density in rural neighbourhoods

We investigated the performance of the proposed scheme also with hop-by-hop communication for low population density neighbourhoods. We did simulations with both the AODV and DSR routing protocols. We used two 10×10 grids representing two consecutive neighbourhoods, as shown in Fig. 3*c*, with the simulation parameters $v = 80$ m, $h = 80$ m and $r = 40$ m. In this scenario, we tried to achieve coverage for houses which are more than 1000 m farther from the bus stop. These houses transmit their data to the bus stop through another house located at the neighbouring grid that is within the communication range of the bus stop. We conducted simulations for only two neighbouring grids, each covering an area of ∼1 km^2, however this scenario could be extended to cover multiple neighbourhoods and longer distances where houses would transmit their data to the bus stop through multiple intermediary neighbourhoods in a hop-by-hop fashion. We repeated all the simulations for 100 times and took the averages for the delivery ratio and end-to-end delay values.

Fig. 7 presents the simulation results for delivery ratio and end-to-end delay with both AODV and DSR. Obviously, both the delivery ratio and delay values are much better with DSR. While a 87.72% delivery ratio is achieved in 56.84 ms with AODV, a 100% delivery ratio is achieved in only 0.56 ms with DSR.

4.5 Overall performance analysis

In Fig. 8, we summarise and compare our simulation results for the proposed smart grid data collecting scheme with both the AODV and DSR routing protocols, and for low, normal and high population density neighbourhoods. As seen in the figure, DSR results in a higher average delivery ratio than AODV for all population densities. Note that the average delivery ratio with DSR is equal to or only slightly <100% for all population densities. Similarly, DSR results in significantly lower average end-to-end delay compared with AODV. Note that in high population density neighbourhoods, the average end-to-end delay with DSR is orders of magnitude lower than that with AODV.

5 Conclusions

With recent advances in WSNs, WSNs have been deployed widely in many applications, e.g. military applications, monitoring applications, health applications, environmental applications, home applications, smart grid environments and vehicular communication. In this work, we merge WSNs with VANETs in a novel scheme for solving the data communication problem in smart grids. We have offered a new data collecting mechanism for smart meters by extending their communication capability to IEEE 802.11p. Changing their communication model, we propose collecting smart grid data from smart meters by using public transportation buses with wireless communication capability. In our proposed scheme, smart meters transmit their data to a bus stop, and then the bus stop transmits the data to a passing-by bus, which in turn transmits it to a central server of the utility company.

We evaluated the performance of our proposed scheme and made simulations with two different routing protocols, namely AODV and DSR, for obtaining end-to-end delay and delivery ratio values. The channel parameters used in our simulations were obtained from a set of field tests at 5.9 GHz in different environments. Our performance evaluations show that the proposed data collecting mechanism achieves significantly better delivery ratio and lower delay when DSR is used.

We identify possible future research directions as follows:

- We transmitted smart meter data of size 100 bytes every 10 min from houses to a bus stop. The influence of varying packet sizes and transmission periods on the efficiency of the proposed scheme may be studied.
- We did not consider the case when a bus would not arrive at the bus stop on its scheduled arrival time. The no show case for a bus may be studied and possible countermeasures could be investigated.
- For houses located more than 1000 m away from the nearest bus stop, we proposed hop-by-hop communication and made preliminary simulations. A more comprehensive study could be conducted on this scenario for a detailed analysis of hop-by-hop communication.
- The security and privacy aspects of the proposed scheme may be studied. Efficient mechanisms may be investigated for communicating smart grid data in a secure and privacy preserving manner in the proposed scheme.
- In the proposed scheme, the IEEE 802.11p communication protocol, which supports a communication range of up to 1000 m, is used. Different wireless technologies may be investigated for the proposed system and their influence on the effective communication distance may be studied.
- In the proposed scheme, one smart meter per building is assumed. For buildings with multiple smart meters, one smart meter (preferably on the top floor of the building) could be picked as the central smart meter which is responsible for collecting data from other smart meters in the building using a wired or a wireless communication technology, then using 802.11p the accumulated data could be sent by this central smart meter to buses. The alternative would be individual data transmissions from all smart meters in a building to buses. Such scenarios extending the capability of the proposed scheme could be explored, and their efficacy and performance could be investigated.
- If buses are passing by an area with high-rise buildings, data transmission from buildings in the back streets may be hindered, which could be mitigated by using multi-hop communication. The influence of unusual or problematic scenarios on the effectiveness of the proposed scheme could be investigated and possible countermeasures could be studied.
- Potential other uses of the proposed technology could be explored, e.g. remote patient monitoring for healthcare applications, where patient data, measured by sensors, is communicated to a physician periodically.

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