Performance and Channel Load Evaluation for Contextual Pedestrian-to-Vehicle Transmissions

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ABSTRACT

Communication between pedestrians' mobile devices and vehicles can play a vital role in improving traffic safety. Enabling such communication is challenging in areas where pedestrian density is high, since transmissions from all pedestrians could lead to high channel load, co-channel interference, and degraded communication performance. To understand these challenges, we first introduce a high-density pedestrian simulation scenario modeled after the Times Square neighborhood in New York City. We then evaluate the channel load in terms of Channel Busy Percentage (CBP) under several contextual safety message trigger policies and different transmission rates. The study uses the Network Simulator 3 (ns-3) with mobility traces generated from a calibrated Simulation of Urban MObility (SUMO) model. The results show that higher transmission rates (5Hz) for all pedestrians lead to high packet error rates, which raises questions about whether application performance requirements can be met at such rates. The results also show that context-aware trigger policies can significantly reduce channel load and lower latency (inter-packet gaps).

Keywords

Pedestrian; Safety; DSRC; P2V; V2P

1. INTRODUCTION

Pedestrians account for a sizable share of traffic fatalities. Even in the United States, where walking is a less common mode of transportation than in other parts of the world, 4,884 pedestrians were killed and more than 65,000 injured in 2014 only [21]. This represents about 15% of traffic fatalities. According to the WHO organization, the share rises to one third in less developed countries [29]. This motivated the research community to develop technologies to increase pedestrian safety.

Previous work has largely considered stand-alone approaches using vehicle sensors, and more recently smartphones, to enhance safety for Vulnerable Road Users (VRU). Automakers have developed camera, RADAR, infrared, and LIDAR based sensors to detect pedestrians in a vehicle's path [13]. Vehicles can use this information to alert drivers or to automatically avoid or reduce the severity of the crash. Recent more exploratory work has investigated whether a smartphone camera can be used while talking on the phone to detect approaching vehicles and warn the pedestrian [28]. All these technologies require line of sight (LOS) between the pedestrian and the vehicle, however. They are inherently less effective when a pedestrian emerges between parked vehicles or in other scenarios where the time to react is too short once line of sight exists.

To create earlier awareness of potentially dangerous situations, even without line-of-sight, researchers have designed collaborative approaches that rely on wireless communications. An example of this category is an RFID-based proximity detection technique that identifies pedestrians at the intersections via Road-Side Units (RSU) and forwards the information to the approaching vehicles [5]. Industry has also demonstrated that smartphones can directly communicate with vehicles using Dedicated Short Range Communication (DSRC) protocols and channels. While much of the DSRC effort has concentrated on allowing vehicles to exchange position information to enhance situational awareness, the recent SAE J2945/9 [24] standardization activities are also explicitly considering vulnerable road users, which includes pedestrians. We refer the reader to this standard document for further details on application scenarios and system design. Here we focus on the network congestion question. Addressing channel congestion and co-channel interference has already required significant work when only considering transmissions between vehicles [27, 8, 15]. This raises questions on how transmissions from potentially large numbers of pedestrians can be accommodated.

To explore and understand the scaling challenges inherent in pedestrian-to-vehicle communications, this paper reports on an effort to evaluate the load generated and the performance achieved in a particularly dense urban environment in the United States. We construct a simulation scenario for the neighborhood surrounding Times Square in New York City and generate pedestrian and vehicle traces using the Simulation of Urban Mobility (SUMO) simulator. These traces are then replayed in the ns-3 network simulator using different pedestrian transmission strategies. In particular, we consider update rates between 1 Hz and 5 Hz for each pedestrian. We also consider contextual trigger policies that activate and deactivate transmissions based on whether the

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pedestrian is moving and whether the pedestrian is located in the street. We report the channel load as well as packet error and latency, in terms of the inter-packet gap achieved in this case study scenario.

In summary, the contributions of this paper are:

- The design, introduction and validation of a challenging high-density scenario for pedestrian safety message evaluations.
- Network performance and channel load evaluations for different transmission policies and update rate assumptions.
- Showing that the the network performance can be significantly improved via contextual transmission policies, such as those prioritizing moving or in-street pedestrians.

2. RELATED WORK

Existing work in the VRU safety literature can be divided into four categories: 1) Sensor-based stand-alone approaches for smartphones; 2) Sensor-based stand-alone approaches for cars; 3) Collaborative approaches using infrastructure; 4) Ad hoc collaborative approaches.

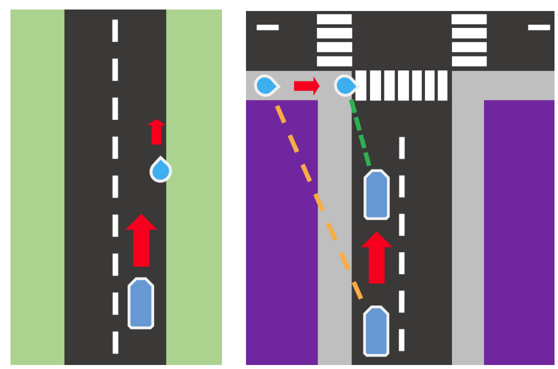
The WalkSafe project [28] is an example of stand-alone applications that uses smartphone camera input to alert the pedestrian if any vehicle is approaching while the pedestrian is using the phone (i.e., talking while walking). In the same category, Jain et al. [17], introduce a new method to alert pedestrians who walk while using their phone whenever they step into the street. This method uses wearable sensors on the pedestrian's shoes paired with the smartphone to detect stepping into the street and can display an alert on a distracted pedestrian's smartphone screen. The presented method is introduced after the authors showed that GPS measurements provided by the smartphones in urban environments are not accurate enough to rely on [16]. These approaches focus on distracted pedestrians, and in their stand-alone form are not a general pedestrian safety solution.

Sensors mounted on vehicles, on the other hand, have potential to detect most pedestrians on the road. Research (e.g.,[10, 25]) that has used different vehicle-mounted sensors such as cameras, RADAR and LASER scanners falls into the second category. While this approach can detect pedestrians that are not using phones and not equipped with special devices, they work only if line of sight to the obstacle is available.

In the third category, as briefly mentioned before, Masud et al. [5] used an RFID tag based communication between pedestrians and cars around intersections via infrastructure equipment (i.e., road side units). While this study shows improved safety, the infrastructure requirement makes it harder to deploy. Sugimoto et al. [26] conducted a pedestrian to vehicle prototype study using 3G cellular communication and IEEE 802.11b WLAN technology. Another paper [7] also describes cellular-based communications between cars and pedestrians, but does not provide any reliability analysis due to high latency in the cellular network in comparison with wifi. Nowadays vehicular communication systems, however, are based on IEEE 802.11p [2]. David and Flach [12] introduce the idea of communication between cars and pedestrians where not all the pedestrians transmit all the time. Since the decision of which pedestrians and cars are at accident risk needs to be made in a server, the system has scalability and other drawbacks of centralized systems.

In 2013, Wu et al. [31] envisioned a future for DSRC technology that supports vulnerable road users such as pedestrians. This work focuses more on the handset battery consumption of the application. Wu et al. further conducted a test-bed study to analyze a Wifi-based P2V communication scenario [30]. While this study includes similar scenarios as those that motivate our research, none of this work has analyzed channel load and scalability of the system. Anaya et al. [6] analyzed some aspects of P2V communications such as the minimum distance required by each party to be successfully warned if the relative speed between the vehicle and the pedestrian is within a threshold. The wireless protocol used in their test-bed, however, is not IEEE 802.11p, which is considered for DSRC communications.

While the majority of previous work in the literature focuses on the different approaches to increase VRU safety, we are not aware of prior research that has examined channel load and scalability questions of a DSRC-based approach.



(a) (b)

Figure 1: General pre-crash scenarios: (a) moving along/against traffic; (b) crossing road

3. SCENARIO AND METHODOLOGY

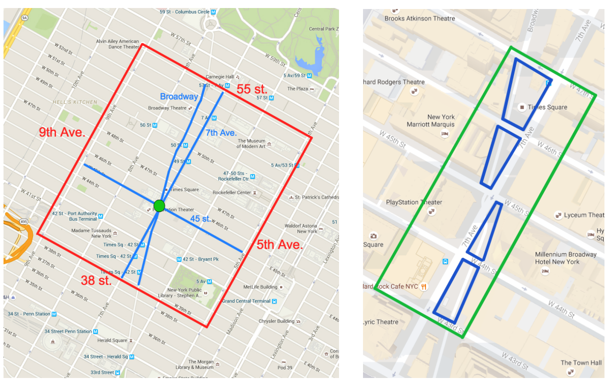
This paper investigates the performance and channel load of a DSRC-based system with different VRU safety message trigger policies and predefined rates by constructing and studying a high-density pedestrian network simulation scenario.

3.1 Pedestrian-Vehicle Accident Scenarios

According to a study conducted by NHTSA in 2014 [32], a traffic accident involving pedestrians is the result of numerous factors including limitations in road geometry, excessive traveling speed of a vehicle, adverse weather, and visual obstruction of human drivers. These factors together lead to delayed or missed detection of a pedestrian. This can be mitigated, as estimated by the study, by equipping vehicles with extra detection capabilities for pedestrians. In the context of this paper, we focus on such capabilities provided by DSRC, where pedestrians carry devices sending DSRC packets to vehicles. We hope that P2V communications can alert the driver or vehicle to the presence of a pedestrian sufficiently in advance to avoid possible traffic accidents.

In particular, we are concerned with the performance of P2V communications in the two scenarios shown in Figure 1. These scenarios represent almost 67% of the total pedestrian fatalities as highlighted in [24]. In the first scenario, a vehicle moves straight with a pedestrian walking against/along traffic. Here, the pedestrian might visible or obscured by other traffic. In the second scenario, a pedestrian could be hidden by objects (e.g., corner of a building), leaving not enough time for the vehicle to brake once detected. These two scenarios require P2V communications work within both LOS and NLOS environments in order to eliminate traffic accidents.

The case for early awareness is further supported by the recent SAE J2945/9 document [24], which indicates 8 seconds before collision as the time requirement for issuing a situation awareness message. Therefore, it is possible that a pedestrian who will cross the street is still on the sidewalk, hidden behind a building from the perspective of the approaching car. Motivated by this consideration, we separately model and analyze line-of-sight and non-line-of-sight communication links in the simulation.



(a) (b)

Figure 2: (a) The area and roads with simulated pedestrian and vehicle traffic (b) Location of stationary pedestrians within Times Square

3.2 Case Study and Simulation Scenario

We selected the Times Square neighborhood in New York City because of its particularly high pedestrian and vehicle density and harsh wireless signal propagation environment, when compared to most other United States locations. It therefore represents a challenging scenario for pedestrian to vehicle communications because the performance of a P2V link depends not only on the channel propagation environment but also on the aggregate interference from other transmitters. It is also a location that faces pedestrian safety challenges. In a 2015 city government safety action plan [22], it has been identified as one of the priority intersection, which require further action to reduce pedestrian accidents. Manhattan overall accounts for 34 out of an average 157 annual New York City pedestrian fatalities.

Figure 2a shows the area we used to create the scenario's topology. Since we focus on examining network parameters at the center of Times Square (i.e. green dot in Figure 2a), the expected point of peak channel load, the selected dimensions are chosen to encompass the maximum interference range in the simulation scenario.

To keep the number of simulated nodes within a computationally feasible range for ns-3, we used a heuristic to further limit the pedestrians represented in the simulator to those that can actually significantly contribute to the channel load at the center of Times Square and impact the system performance. The path loss exponent between a pair of transceivers that are located on two different sides of a building is very high (see Section 3.3). This means that the spatial channel load for two parts of the map with a building between them are almost uncorrelated. We therefore retained only generated pedestrian and vehicle traffic in immediately adjacent streets (the area within the green box in Figure 2b) and for the roads where line-of-sight to the center of Times Square exists (marked by blue in Figure 2a).

(a) Taken Between 46 St. and 47 St. looking south

(b) Taken at 48 St. and 7th Ave. intersection, looking north

Figure 3: Sample photograph footage used to validate the simulated mobility traces

The pedestrian and vehicle traffic traces are generated using the SUMO mobility simulator [9]. The resulting mobility traces, are further calibrated using more than three hundred photos we took during peak hours in the area. SUMO generates vehicle and pedestrian movement traces using Origin-Destination models. The primary model uses a graph representation of the map, where vertices and edges represent intersections and streets, respectively. Then entities such as pedestrians and vehicles can be generated for a pair of origin and destination edges. The density and general movement pattern can be further controlled by manipulating parameters such as the maximum walk distance, the probability of origin and destination edges at the map's margin, etc.

Given the goal to evaluate channel load and interference, we focused on matching the overall distribution and movements of pedestrians in a short, say 10s simulation. Since we do not require long simulation times, we did not attempt to create accurate origin-destination models for pedestrian trips. Figure 3b is an example photo used to calibrate the density of moving pedestrians by providing number of pedestrians waiting for green traffic light to pass a particular intersection in the aforementioned map. We adjusted the pedestrian traffic flow parameters in the SUMO simulator until the count at the same intersection in the mobility trace approximately match the one obtained from the photo.

In the Times Square area marked by dark blue in Figure 2b, most pedestrians linger and do not move for periods of time. Those pedestrians are not well-represented by SUMO default models. We therefore decided to create 400 additional pedestrians in Times Square, which are modeled as stationary given our short simulation time. We used photos such as Figure 3a to match the distribution and the number of stationary pedestrians in Times Square, between 44 Street and 47 Street.

Note that only the movement for pedestrians and vehicles which are outdoors is modeled; people inside buildings, and vehicles parked in indoor parking areas are not included in the mobility traces even though they could also contribute to interference, albeit at somewhat lower levels due to building attenuation.

The resulting scenario comprises approximately 400 vehicles and 2000 moving pedestrians across 7th avenue, 45 Street and Broadway, and 400 stationary stationary pedestrians at peak time across Times Square. [1]

3.3 Propagation Environment

To better reflect the propagation environment in a densely-built urban environment, we designed the simulator to choose different models depending on the degree to which the direct path is obstructed between a sender and receiver. The simulator maintains a map of building outlines (obtained from OpenStreetMap) and uses these to distinguish three situations: No-Building Shadowing (NBS), Building Shadowing (BS), and Building Blocked (BB). Figure 4 illustrates these link categories. From a simulation perspective, whenever there is a packet transmission, the propagation loss module within the simulator identifies the matching category for the link and then calculates the received signal according to the corresponding propagation model. We describe the exact selection criteria and models next.

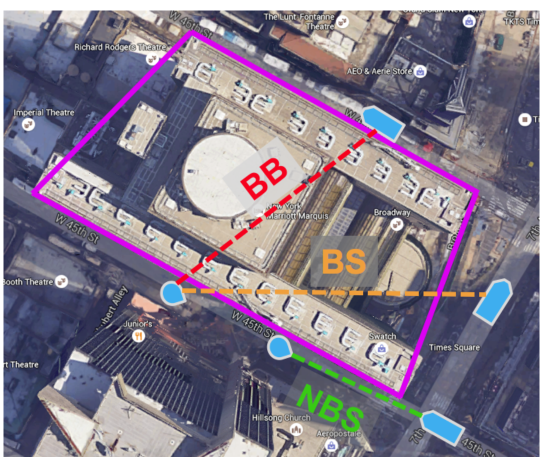


Figure 4: Different link types between transceivers

NBS Links: If the direct path between two transceivers does not intersect any of the building edges, then the link is classified as not being affected by building shadowing and blocking. We apply propagation loss model associated with NBS links as Log Distance and the fading model as Nakagami with the parameters specified in [19]. An example of this type of link is shown in Figure 4 where the link color is green.

BS Links: If the line is intersecting two adjacent edges of the same building, then the link between them is considered as a wireless link with building shadowing, where the two transceivers share an intersection that they have LOS access to its center. We label this category of links, which is showed with yellow color in Figure 4, with BS. Mangel et al. [19] introduce a propagation loss model for the case where two transceivers share an intersection. The aforementioned model fits to the BS links characteristics in our study, and therefore, is implemented as the associated propagation loss model for the BS links within the simulator.

BB Links: The third category is where the link between two transceivers is blocked by a building. But, in this case, the two transceivers do not share an intersection, i.e. they are located in parallel streets (see the red color link in Figure 4). Considering the height and depth of the buildings in Manhattan area, we assumed the signal strength on the other side of the building would be negligible and the interference is not accounted for in the simulation. If there is more than one building between the transceivers, the link is considered as BB as well.

Table 1 summarizes different links categories based on the relative transceiver and and building's locations.

Table 1: Propagation Environment Summary

Acronym	Link Type	Associated Loss Model
NBS	No Building Shadowing	Log Distance and Nakagami models with parameters in [19]
BS	Building Shadowing	Proposed loss model in [19]
BB	Building Blocked	Constant infinite loss

3.4 Transmission Trigger Policies

We assume that the pedestrian transmission will be activated by a trigger policy since it is undesirable to contribute to channel congestion and handset battery drain when the user is in no need protection. By exploiting rich sensor data from a smartphone, the generation of VRU safety message can be context-based, i.e., the message generation is only triggered in certain situations that can be detected with smartphone sensors. Based on a review of relevant context-detection literature, we select three possible trigger conditions for further study. Note that the focus of this paper is not on developing these context sensing technologies but to evaluate their effectiveness in contextual trigger policies, assuming that the sensing itself can be realized. Table 2 summarizes relevant context sensing technology.

Table 2: Sensing Technology Assumptions for Smartphones

Outdoor Environment Detection	The device is able to distinguish outdoor environments from indoor [33, 18]
Movement Detection	The device is able to detect movements, e.g. using accelerometer [20]
Approaching Road Detection	The device is able to detect crossing a road using, e.g. GPS or other sensors [17]
In-vehicle phone detection	The device is able to detect if it is in a vehicle [14]

Based on the technology assumptions in table 2, the considered VRU safety message transmission policies are:

[1]The mobility traces and ns-3 simulator source code are available for download [4].

Baseline (Outdoor): All pedestrians located outdoor periodically generates a safety message at fixed transmission rate r. Specifically, we consider rates of 1 Hz, 2 Hz, and 5 Hz. We selected those rates with the goal of enabling the receiver to track the position of a moving pedestrian. Lower rates would lead to considerable movement of a running pedestrian in between updates. Higher rates would not offer a tracking benefit considering expected pedestrian speed and achievable positioning accuracies. Note that indoor persons are not included in our simulations, since there normally is no risk of traffic accidents. We also assume that phones in vehicles do not transmit because vehicles are planned to have built-in DSRC transmitters.

MovingPed: This contextual trigger policy activates transmissions at the fixed rate r only when the pedestrian is outdoor and moving. Transmissions begin immediately when movement is detected and continue for a time window S after the phone last senses movement. Mobile smartphones in vehicles are assumed not to transmit.

Multiple Tx Rates: This algorithm allows all outdoor pedestrians to transmit but at different rates depending on whether they are stationary or moving. Moving pedestrians transmit at the faster 5Hz rate and stationary pedestrians transmit at the slower 2Hz rate. Again, mobile smartphones in vehicles are assumed not to transmit.

On-StreetPed This policy only allows pedestrians that are located on streets to transmit at a fixed rate r. Sensing technology to support such distinctions is less mature than movement and in-vehicle detection but we include it here for reference since knowing about such pedestrians is presumably more relevant to vehicles than the many pedestrians that are safely located on sidewalks.

4. EVALUATION

To evaluate channel load, test-bed implementation would be very expensive regarding the scale of the scenario. Instead, we use ns-3.16 [1] with Wifi frame capture [3] to simulate the communication between pedestrians and vehicles. The list of simulation parameters is given in table 3.

Table 3: Simulation Parameters

Parameter	Value
CW_{min}	15
AIFSN	2
Packet size	316 bytes
Data rate	6 Mbps
Transmission power	20 dBm
Noise floor	-98 dBm
Energy detection threshold	-85 dBm
Simulation time	10 sec

We use three metrics to evaluate simulation results: Channel Busy Percentage (CBP) as the indicator of channel load, Packet Error Ratio (PER) and near worst case Inter-Packet Gap (95% IPG). These are typical link quality parameters in the V2V safety communication research [23, 11]. CBP is calculated using Eq. 1.

$$CBP = \frac{t_{ChBusy}}{t_{CBP}} \times 100\% \qquad (1)$$

Where t_{CBP} is the CBP measurement window and t_{ChBusy} is the time period during which the channel is measured as busy by the device. PER is the ratio of the number of dropped messages to the sum of the received and dropped messages for each pair of transmitter and receiver. Likewise, IPG measures the time between two consecutively received packets between a pair of transmitter and receiver. IPG is an important performance metric since it determines how frequently a vehicle could get information updates, such as the location, from a particular pedestrian. The near worst case analysis for IPG helps to understand how bad the system might perform.

The PER and 95% IPG are calculated based on the transmissions carried out in Times Square area (the green box in Figure 2b). That is, if the transmitter is within the green box the transmission is accounted for computation regardless of whether the receiver is within the same region or not. Since vehicles are probably less interested in getting updates from a pedestrian located on a parallel road (not opposite lanes on the same road), where there is a building between them, all the BB links are excluded. The distance between transmitter and receiver determines in which distance bin the transmission (successful/unsuccessful) is counted. The distance bin is set to 30 meters in this paper.

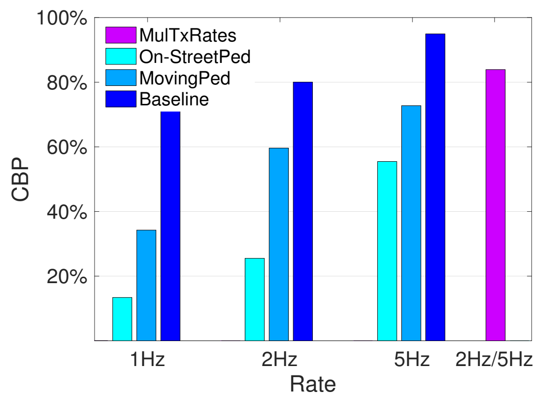


Figure 5: Measured CBP at the center of Times Square

Figure 5 shows average CBP over 10 seconds of simulation for different rates and different transmission trigger policies at the center of Times Square (green circle in Figure 2a). The simulation initialization phase, further, has been removed from the calculations. Since, so far, there is no standard on the issue of the VRU safety message generation rate, all the performance and channel load evaluations are done where the VRU safety message transmission rate r is 1 Hz, 2 Hz, or 5 Hz, which means that VRU safety messages are transmitted every 1 second, 500 milliseconds or 200 milliseconds, respectively, once the policy's constraints are met. As Multiple Tx Rates (labeled as *MulTxRates* in the figures) is a policy using both 2 Hz (Stationary pedestrians) and 5 Hz (Moving pedestrians). Its results are shown separately with the single bar.

While the argument against lower safety message transmission rates is that they simply might not meet the minimum safety requirements regarding the location updates, Figure 5 shows that the channel easily gets saturated when the frequency of safety message transmission grows. On the other hand, the baseline transmission policy shows worst performance. Simulation results show 94% as CBP for Baseline $r = 5Hz$ due to transmissions of hidden nodes from dif-

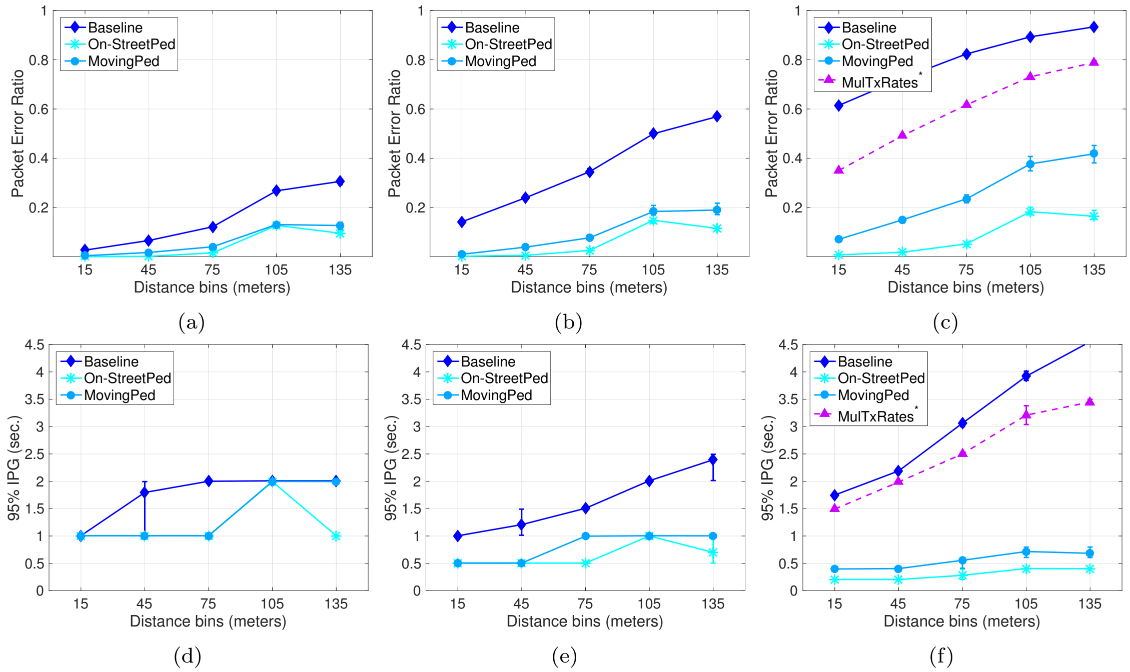


Figure 6: PER and 95% IPG analysis for NBS and BS links: (a) PER for $r = 1Hz$; (b) PER for $r = 2Hz$; (c) PER for $r = 5Hz$ (d) 95% IPG for $r = 1Hz$; (e) 95% IPG for $r = 2Hz$; (f) 95% IPG for $r = 5Hz$
* Stationary pedestrians transmit at $r = 2Hz$ and moving pedestrians transmit at $r = 5Hz$

ferent streets, which is high enough to saturate the channel. MulTxRates holds the second busiest channel among other policies and rates with CBP 84%.

Figure 6 shows performance metric analysis based on simulation results. Each metric calculation in this figure is averaged on five simulation runs with different mobility traces. The error bars on each distance bin result represent minimum and maximum over all five simulation runs.

Figures 6a-6c show PER for different VRU safety message transmission policies where the transmission rates are $r = 1Hz$, $r = 2Hz$ and $r = 5Hz$, respectively. For each of these PER plots, the corresponding 95% IPG results are presented in Figure 6d-6f. It can be seen that the PER increases dramatically where no transmission constraints are used other than the outdoor detection. Figure 6f shows that a high PER for Baseline can further lead to undesirable IPG results. Normally, the higher the 95% IPG, the less reliable the system is.

Some of the PER and 95% IPG results for 135m are lower than at 105m distance, which seems surprising. In the simulation logs, we found that the 105m bin contains more samples from BS links, which has worse communication performance than NSB links, than the 135m bin. We believe that this is an artifact of the building layout in this particular environment.

Another observation from Figure 6 is that the system is significantly more reliable as the given transmission rate increases up to 5 Hz when MovingPed or On-StreetPed used. This is also consistent with the observation from Figure 5, where the channel is not optimally used, suggesting that there could be even more packets on the air in a given time interval. Not surprisingly, MulTxRates still has the second worst performance among all rates/policies.

Although the presented results in Figure 6 for some of the transmission trigger policies are promising, note that performance analysis is done for the overall PER and 95% IPG in terms of different link types. As briefly mentioned in Section 3.1, there might be some special cases of the crossing road pre-crash scenario where the pedestrian is not in the driver's sight at the time that the first situation awareness transmission is needed to be delivered to the vehicle. In such cases, if the VRU safety message is delivered once the pedestrian moved to a LOS situation, the situation awareness alert time requirement specified in SAE J2945/9 might not be met before estimated TTC [24].

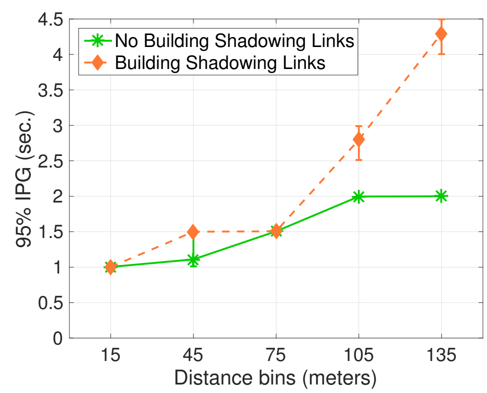


Figure 7: 95% IPG for Baseline $r = 2Hz$ for different link types

This is why we further split the results shown in Figure 6e based on the type of the wireless links at the time of communication. Figure 7 compares the 95% IPG for NBS and BS links. The figure shows a 40% to more than 100% jump in 95% IPG for the BS links in comparison with the NBS links at higher distance bins, where the system functionality might mostly rely on BS links.

5. DISCUSSION

Let us briefly discuss channel choice implications of these results and the impact of frame capture in these simulations.

5.1 Channel Choices

To enable vehicle to pedestrian communications, decision have to be made around the world on which channels to permit transmissions from mobile handsets. The simulations in this work have only considered pedestrian transmissions on a 10 MHz/6 Mbps DSRC channel with no other traffic. The channel load and performance results therefore best represent the results obtained with a dedicated channel for pedestrian to vehicle communications, which is separate from all other DSRC-related messaging. Receiving such messages would then require an additional radio in cars that is tuned to this channel. One might also ask whether such messages can be accommodated on the safety channel used for vehicle-to-vehicle safety messaging. Given the relatively high channel loads obtained even with contextual triggers for moving detection, it is questionable whether a 10 MHz channel offers enough capacity for both vehicle and pedestrian messages. It is possible, though, that future work will lead to improved sensing strategies that can identify particularly dangerous traffic situations involving pedestrians, which could allow for such transmissions.

5.2 Impact of Frame Capture Implementation

Frame Capture is a feature of modern wireless chips that allows switching to receiving a newly arrived signal with a stronger signal strength when a reception of a weaker signal was already in process. While to date, the official release of the ns-3 simulator does not support this feature, we implement the frame capture effect in our simulator by applying patches we have developed [3]. To emphasize the importance of the capture effect model in these simulation studies, we repeat some of the experiments with the default ns-3 packet reception model (i.e., without frame capture).

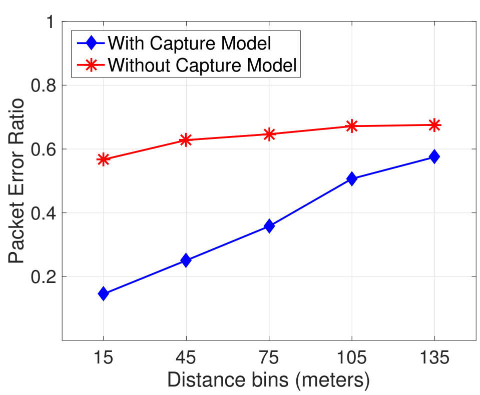


Figure 8: PER for Baseline $2Hz$, with/without wifi frame capture feature in the simulator

Figure 8 compares the PER where the simulator is using the default ns-3's packet reception model with simulator using Wifi frame capture. All the other simulation settings and the scenario configuration are kept. Note that the simulation results show up to 40% increase in PER when the default ns-3 packet reception model is used. This is mostly because at short distance bins, the wifi frame capture feature is able to lock to a stronger frame coming from a nearby device. On the contrary, the default ns-3 packet reception model drops both the currently receiving packet and the newly arrived packet.

6. CONCLUSIONS

In this paper, we first created a simulation scenario for Times Square area in New York City and generate pedestrian and vehicle traces using the Simulation of Urban Mobility (SUMO) simulator. These mobility traces were further replayed in the ns-3 network simulator to evaluate channel load and performance of such a network. The evaluation is done considering sample transmission trigger policies that prioritize moving pedestrians or on-street pedestrians where the transmission rate is varying between 1 Hz and 5 Hz. Extensive simulation results show that results for the 5 Hz transmission policy, where the smartphones transmit at 5 Hz when an outdoor environment is detected (Baseline policy) raise questions on whether vulnerable road user performance targets can be met in crowded environments. It also has been shown that there exists significant potential to improve the network performance through context-aware transmissions policies or trigger conditions.

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