

# Cellular-based Vehicle to Pedestrian (V2P) Adaptive Communication for Collision Avoidance

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**Abstract**—Road safety is one of the most important applications of vehicular networks. However, improving pedestrian safety via vehicle-to-pedestrian (V2P) wireless communication has not been extensively addressed. In this paper, our vision is to propose a method which enables development of V2P road safety applications via wireless communication and only utilizing the existing infrastructure and devices. As pedestrians' smartphones do not support the IEEE 802.11p amendment which is customized for vehicular networking, we have initiated an approach that utilizes cellular technologies. Study shows potential of utilizing 3G and LTE for highly mobile entities of vehicular network applications. In addition, some vehicles are already equipped with cellular connectivity but otherwise the driver's smartphone is used as an alternative. However, smartphone limited battery life is a bottleneck in realization of such pedestrian safety system. To tackle the energy limitation in smartphones, we employ an adaptive multi-level approach which operates in an energy-saving mode in risk-free situations but switches to normal mode as it detects a risky situation. Based on our evaluation and analysis, this adaptive approach considerably saves electrical energy and thus makes the cellular-based road-safety system practical.

**Keywords**—pedestrian road safety; V2P; battery life; cellular network; smartphone

## I. INTRODUCTION

One of the most important applications of vehicular networks is improving road safety. Although pedestrians are among vulnerable road users in fatal accidents [1], most of the previous research on road safety via vehicular networks has focused on vehicle to vehicle accidents and thus improving pedestrian safety has not been extensively addressed. Integrating pedestrians into the vehicular networks by means of their smartphones enables development of several road safety applications such as vehicle to pedestrian (V2P) collision avoidance [2], [3].

However, smartphone suffers from shortage of electrical energy due to limited battery capacity. Therefore, although there are plenty of solutions proposed for V2V scenarios, not all those solutions are directly applicable to the V2P applications. In addition, accident risk should be decreased in both blind sight and non-blind sight scenarios. There is no line of sight in blind sight scenarios (e.g. when pedestrian steps on the road from behind a parked vehicle) and therefore it is much harder for drivers to notice the pedestrian in time and avoid the accident.

Pedestrian safety solutions can be based on two classes of pedestrian detection methods: (a) classic sensor based [4], [5], [6] which employs sensors such as RADARs, LASER scanners, IR sensors and imaging sensors (computer vision), and (b) wireless communication between vehicle and pedestrian [7], [8]. Almost all of previous pedestrian safety solutions (prototypes or commercially deployed) are based on the first class of methods. Their major drawback is their dependence on line of sight for detecting obstacles (i.e. pedestrians), which makes them unusable in blind sight conditions [4], [7]. Sensors mounted on the vehicle have a limited line of sight and implementing infrastructure-based systems is expensive and only practical in certain scenarios [4]. In addition, reliability of detection decreases in poor visibility conditions (e.g. low brightness). As a result, in recent years, more attention has been paid to integrate the second class of solutions (using wireless communication) with classic sensor-based methods in order to improve pedestrian road-safety [7], [8], [9], [10].

Our vision is to propose a method that enables development of pedestrian safety systems which use V2P wireless communication (second class of solutions mentioned above) and only utilize existing infrastructure and devices. In other words, due to costs of production, installation and the long market penetration and user adoption period, we aim at using current infrastructure and communication technologies as much as possible. Therefore according to this vision, a prospective V2P networking solution should not require installing new hardware (e.g. should not be dependent on the road-side units). In this regard, authors of [7] and [8] have employed existing infrastructure and devices (namely smartphones, and a combination of WiFi communication and cellular-based Internet) for pedestrian safety. However, utilizing WiFi is not practical in all collision prevention scenarios. The reason is the problem of interference with other networks (particularly problematic in urban areas whereas rural areas), limited communication range of WiFi (100 meters) and weak mobility support (e.g. sensitivity to Doppler effect due to its 20 MHz channel width) [11], [12]. Following the Dedicated Short Range Communications (DSRC) method, the IEEE 802.11p amendment is specifically standardized for vehicular networks and addressed the interference, mobility and communication range problems. However, 802.11p requires dedicated hardware which is not available on commercial vehicles yet, and the effort to adapt it for smartphones has been only recently started by a few companies [9], [13].

We propose utilizing smartphones and cellular technologies as the communication method for V2P applications. Although these technologies (e.g. 3G and LTE) are not designed for vehicular networks, evaluation ([7], [12]) and experiment ([8], [14]) show their potential for this purpose. This is because of their high mobility support, and high bit-rate, communication range and capacity [12]. Some vehicles are already equipped with cellular connectivity (on-board SIM card) but otherwise the driver's smartphone can be used as an alternative. In this regard, authors of [14] have employed cellular-based Internet (3G HSDPA) to implement their pedestrian and cyclist safety prototype. In addition, unlike a DSRC-based ad-hoc approach, the cellular-based approach more easily allows cloud-based computation (using central-servers).

The problem is that limited battery life of smartphone is a bottleneck in realization of such pedestrian safety system. In order to predict accidents, both pedestrian smartphone and vehicle need to constantly and with a high frequency (very short intervals) send updates containing their location, speed and direction. These periodic messages, even when sending small amount of data, can drain the smartphone battery very quickly. In this paper, we investigate this problem by evaluating the overhead of road-safety system on energy consumption of smartphones.

In this paper, we make the following contributions:

- In order to save electrical energy in smartphones and thus enable running the pedestrian safety system, we propose an adaptive multi-level approach which changes the messaging frequency according to traffic density and level of risk.
- We perform energy consumption analysis for both adaptive and non-adaptive approaches in order to evaluate how much overhead the pedestrian road safety system imposes on smartphone battery life. This analysis is performed with different arrangements of our adaptive approach, different smartphones in terms of energy-efficiency, and with different traffic and daily life scenarios. Analysis concludes that our adaptive multi-level approach is practical for running pedestrian safety systems using mainstream smartphones. It also shows the considerable benefit of adaptive approach in terms of energy-efficiency and battery life in comparison to non-adaptive approach.

## II. RELATED WORK

Regarding communication in the system, two main types of safety messages have been defined by ETSI for the road-safety class of vehicular networks applications [15]: (1) Cooperative Awareness Message (CAM) (beacons) which is time-triggered (periodic) and conveys position information. Data traffic can be heavy and frequent which might result in heavy energy consumption or considerable data exchange charges by operators to drivers and pedestrians, (2) Decentralized environmental notification message (DENM) which is event-triggered and conveys hazard warnings. Example of a DENM message for pedestrians is traffic light violation warning on their smartphones. This type of message allocates less data

traffic and has a limited lifetime. ETSI specifies maximum allowed latency of 100 ms for CAM and DENM messages as well as the time interval between CAM messages ranging from 0.1 s (100 ms) to 1.0 s depending on the use case [16]. For this purpose, LTE has a fair enough performance with a maximum latency of 100 ms [12]. In addition, authors of [7] demonstrate feasibility of using earlier cellular technologies such as UMTS and HSPA by means of practical experiments.

Regarding computation, the predictive algorithm, pedestrian detection and collision prevention can be performed in one of the following methods [7] and the choice depends on which method provides a better performance and energy efficiency: (a) all computation performed on smartphone, (b) all computation performed on vehicle on-board unit (OBU), (c) all computation performed on back-end servers. In this paper, we adapt and use only the last method (cloud-based server). This method has the advantage of having access to road information such as maps which in turn allows performing more precise or advanced calculations and better predictions.

As mentioned before, there are a few similar works ([7], [8], [14]) which employ cellular-based methods for pedestrian safety. In [7], authors have explained the whole domain considering both ad-hoc (using WiFi family of protocols) and cellular methods, and with different architectural arrangements. They also address the non-structured movements and behavior of pedestrians by using “filters” in order to identify and ignore non-risky movements. Authors of [8] address the architecture choice, develop a V2P prototype and perform simulation based on their method. They use cellular network (3G) to send GPS data to a server. Initial and predictive calculation is performed in the server and in case this calculation concludes a risk, vehicles and pedestrians are informed. After this notification, a direct V2P communication is started using WiFi. Authors of [14] experiment and analyze the accuracy of GPS information provided by smartphones, and feasibility of using 3G Internet in terms of latency.

Unlike [7] and [8], we use cellular network for communication in all cases and no switching is performed between cellular and 802.11p (or regular WiFi) when a risky situation is detected by the cloud-based server. Finally, unlike the previous solutions, we analyze the road-safety system in terms of energy consumption and propose an energy efficient approach, specifically while using the battery-limited smartphones as the main communication device for V2P networks.

## III. ADAPTIVE MULTI-LEVEL METHOD

In our road-safety system, we consider a design based on mobile cloud computing where servers perform all the data processing and computation whereas road users (pedestrians, vehicles, cyclists) only send update messages to the cloud-based servers. These messages contain *speed*, *location* and *direction* (obtained from GPS or Galileo). This basic information alone is enough for the system to anticipate possible collisions. Pedestrians use a smartphone to establish communication to the cloud via cellular network (e.g. 3G, LTE) and vehicles utilize either a cellular module (with a dedicated SIM-card) or driver's smartphone. We identify

whether the smartphone is being used by the vehicle (named “vehicle’s smartphone” in this paper) when it is plugged to vehicle’s electricity system, or by using novel methods such as the one developed by authors of [17]. Otherwise, we consider that the smartphone is being used by a pedestrian.

Each road user involved in a risky situation (e.g. a situation which may lead to a collision) should send the update messages in a periodic fashion. These messages are in CAMs category [15] which according to use cases defined by ETSI (“Collision Risk Warning” and “Intersection Collision Warning”) should be generated with a 0.1 s (100 ms) interval [16]. However as explained in section I, such arrangement is not practical in terms of energy consumption due to the limited battery source of smartphones.

We propose an adaptive multi-level method which saves electrical energy by reducing unnecessary network traffic that is caused by constant radio-level beaconing. Fig. 1 illustrates the system workflow in our approach. Pedestrian’s smartphone and vehicle’s smartphone perform the beaconing (no listening on these smartphones) while the cloud-based server performs the more frequent and power-hungry operation of listening as well as calculations for collision prediction.

Pedestrians are in risk-free situations at many times, such as when they are walking along streets without crossing or when they are not in enough proximity to any road or vehicle to be considered a risky situation. In such risk-free situations a constant full-rate beaconing is not required. In order to address this problem, we develop two levels (modes) of operation only for pedestrian’s smartphone: *low-rate* and *full-rate*. The pedestrian’s smartphone works in an energy-saving mode (low-rate mode) in risk-free situations where the beaconing frequency is kept at a lower rate. A predictive algorithm is running by the cloud-based server at the same time. When a risk-prone situations arises (such as when the pedestrian approaches towards the road in order to cross it or reaches certain proximity of vehicles), the predictive algorithm recognizes the change of situation and adapts the system accordingly. It sends push message to alert the pedestrians’ smartphones to switch to full-rate mode.

In our system, vehicle’s smartphone works in full-rate mode all the time. We assume that vehicle’s smartphone is plugged to vehicle’s electricity system using a car adapter, and therefore does not have energy limitation problem. However, if such arrangement does not exist, for example if driver forgets to plug the smartphone, then innovative methods [17] can be used to alert the driver about this problem.

Table I summarizes parameters which have influence on the results of our approach. The rest of this section explains

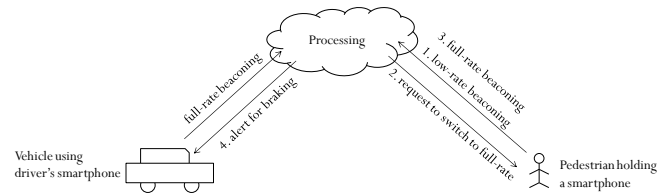


Fig. 1. System work flow and messaging order.

these parameters and their calculation in more detail.

#### A. Beacon Interval

We need to quantify the maximum beacon interval ( $i_{max}$ ) possible for the low-rate mode in order to have a practical system setting. Fig. 2 illustrates the process during a collision avoidance scenario. As soon as distance between a vehicle and pedestrian and their movement direction and speed indicate a risky situation, the system starts a full-rate communication to perform further processing. In case a possible collision is predicted, server informs vehicle’s smartphone with a critical alert. At this point, driver activates the brakes and makes the vehicle stop. The distance traveled by the vehicle during this whole process is named *process & brake window* ( $w_{process\&brake}$ ). The collision avoidance algorithm takes into account vehicles and pedestrians only in a limited range of *maximum distance window* ( $w_{max}$ ) as shown in Fig. 2. This range depends on the system settings as well as the maximum relative speed ( $v$ ) supported.  $v$  is the vehicle speed before brakes are activated and pedestrian’s speed is assumed 0. Considering  $w_{max}$ , our system has an *extra distance window* ( $w_{extra}$ ) before starting the accident prevention processing.

$$w_{extra} = w_{max} - w_{process\&brake} \quad (1)$$

The system should switch to the full-rate interval mode inside this  $w_{extra}$  and at the latest right before  $w_{process\&brake}$  starts. The delay caused by beaconing interval of low-rate energy-saving mode causes a *distance gap*. This *distance gap* should not exceed  $w_{extra}$ , otherwise, system may receive the beacon indicating a risky situation late. Consequently, switching to the full-rate beacon mode will be also delayed which might lead to a collision. Based on this discussion, we conclude equation (2) for the  $i_{max}$ .

$$i_{max} = (w_{max} - w_{process\&brake}) / v \quad (2)$$

$w_{max}$  is defined as a constant value (calculated in next section) and value of  $v$  is sent to cloud server by the vehicle.  $w_{process\&brake}$  is calculated as follows.

$$w_{process\&brake} = d_{processing} + d_{reaction} + d_{brake}$$

$$w_{process\&brake} = v \times t_{process} + v \times t_{reaction} + v^2 / (2a_{brake}) \quad (3)$$

$$t_{process} = t_{comm} + t_{comp} \quad (4)$$

$d_{processing}$  is the distance travelled by vehicle while the system is performing communication and computation required to predict a collision. This collision prediction process takes  $t_{process}$  (4).  $t_{comm}$  comprises transmission times of beacon message from smartphone to cloud server and brake alert from

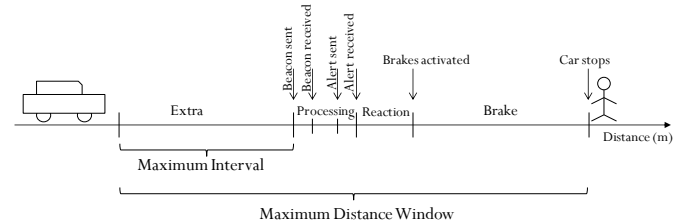


Fig. 2. A worst case scenario for vehicle to pedestrian collision avoidance based on wireless communication.

TABLE I.

PARAMETERS INFLUENCING THE ADAPTIVE ROAD SAFETY SYSTEM.

Parameter	Description	Value
$W_{max}$	Maximum distance window (processing range)	200 m
$i_{max}$	Maximum beacon interval	A function of $v$
$t_{process}$	Time spent for collision prediction	0.06 s (60 ms)
$t_{reaction}$	Reaction time until brakes are activated	0.83 s [19]
$\{v, d_{brake}\}$	Car speed and associated brake distance based on statistical data	Refer to [18]
$a_{brake}$	Deceleration during brake	6.5 m/s <sup>2</sup>
$i_{low-rate}$	Low-rate beacon interval	$i_{max}$
$i_{full-rate}$	Full-rate-beacon interval	100 ms
$t_{fullrate}$	Duration of time the system is running in full-rate mode	Depends on several factors such as traffic volume, city area and pedestrian mobility pattern
$C$	Smartphone battery capacity	7.98 Wh
$P_0$	Typical power consumption of different smartphones (without road-safety system)	{1.5 W, 0.5 W, 0.15 W}
$P_{fullrate}$	Additional power consumed by road-safety system in full-rate mode	1.216 W
$P_{lowrate}$	Additional power consumed by road-safety system in low-rate mode	A function of $v$ and its associated $i_{low-rate}$
$t_{transmit}$	Beacon message transmission time	0.00008 s
$t_{tail}$	LTE tail	0.1 s for low-rate and 0.09992 s for full-rate mode
$P_{transmit}$	Power consumption of one beacon transmission	1.52 W
$P_{tail}$	Power consumption of tail	1.216 W
$t_0$	Typical battery life of different smartphones (without running road-safety system)	{5 h, 16 h, 53 h}
$t_{overhead-adaptive}$	Overhead of adaptive method on smartphone battery life	A functions of $i_{low-rate}$ , $t_{fullrate}$ and $t_0$

server to vehicle, which is equal to the average ping response time from smartphone to cloud server.  $t_{comp}$  is the run time of predictive algorithm.  $d_{reaction}$  is the distance travelled by vehicle while the driver is reacting to the alert and before brakes are activated. Therefore  $t_{reaction}$  comprises both driver's reaction time and brake activation delay.  $d_{brake}$  is the distance travelled after brake activation until the vehicle completely stops.  $a_{brake}$  denotes the vehicle deceleration when brakes are activated and its value depends on the type of car (how good the brakes are) and road conditions (e.g. type of pavement, wet or dry road).

### B. Energy Consumption and Battery Life

We need to quantify the overhead of our adaptive method on smartphone battery life ( $t_{overhead-adaptive}$ ) and also quantify the energy consumption improvement achieved over a non-adaptive always full-rate method.  $t_{overhead-adaptive}$  is calculated by (5) where  $t_0$  (in hours) is typical battery life without running any pedestrian safety system and  $t_{adaptive}$  is battery life while our adaptive road-safety system is active.  $C$  (in mWh) denotes the capacity of the battery and  $P_{adaptive}$  (in W) denotes the amount of power that smartphone consumes by running only our adaptive safety system.  $P_0$  is the typical power consumption of the smartphone itself (daily use, without running the adaptive road-safety system) which its value varies depending on smartphone model and user habits.

$$t_{overhead-adaptive} = (t_0 - t_{adaptive}) / t_0$$

$$t_{overhead-adaptive} = 1 - (C / (P_0 + P_{adaptive})) / (C / P_0) \quad (5)$$

Getting into more details,  $P_{adaptive}$  is calculated by formula (6).  $P_{fullrate}$  is the amount of additional power smartphone consumes while running our adaptive system in the full-rate mode and  $P_{lowrate}$  is the additional power consumed in the low-rate mode.  $P_{adaptive}$  also depends on the duration of time (e.g. number of hours) pedestrian spends near traffic-prone areas,

which depending on traffic density and speed of cars causes the smartphone to perform in a full-rate mode ( $t_{fullrate}$ ) rather than the low-rate mode ( $t_{lowrate}$ ). Therefore, the denser and faster the traffic is, the more fraction of time during a certain time period (e.g. a full day) is spent in a full-rate mode.

$$P_{adaptive} = (t_{fullrate} \times P_{fullrate} + t_{lowrate} \times P_{lowrate}) / (t_{fullrate} + t_{lowrate}) \quad (6)$$

$P_{lowrate}$  and  $P_{fullrate}$  are calculated by (7) and (8) respectively. More details about power consumption calculation is presented in [23]. In summary, in order to send a beacon message, the system firstly needs to turn on radio. The radio consumes  $P_{tail}$  mW power while it is on and it goes off after  $t_{tail}$  ms. In addition, the system needs to transmit the beacon message through cellular network which takes  $t_{transmit}$  ms and consumes  $P_{transmit}$  mW. Finally, value of  $i_{low-rate}$  (low rate interval) is equal to the  $i_{max}$  (2) and value of  $i_{full-rate}$  (full rate interval) depends on the system settings.

$$P_{lowrate} = (P_{tail} \times t_{tail} + P_{transmit} \times t_{transmit}) / i_{low-rate} \quad (7)$$

$$P_{fullrate} = (P_{tail} \times t_{tail} + P_{transmit} \times t_{transmit}) / i_{full-rate} \quad (8)$$

Likewise, overhead of a non-adaptive method on battery life ( $t_{overhead-nonadaptive}$ ) is calculated by (9). The only difference is that in contrast to the adaptive method, a non-adaptive approach performs beaconing with a full-rate interval at all times and therefore the power it consumes is simply calculated as  $P_{nonadaptive} = P_{fullrate}$ .

$$t_{overhead-nonadaptive} = (t_0 - t_{nonadaptive}) / t_0 \quad (9)$$

## IV. EVALUATION

Values of  $w_{process\&brake}$  (3) and  $t_{process}$  (4) are calculated as follows.  $t_{comm}$  (comprising both beacon message and alert message send times) is equal to the average ping response time over LTE and assumed to be 50 ms [20]. The computation part

( $t_{comp}$ ) is rather lightweight and mainly needs the location, speed and direction of each vehicle/pedestrian pair in order to anticipate a possible accident. We assume that this computation only takes a maximum time of 10 ms. As a result,  $t_{process}$  equals 60 ms (0.06 s) which is less than the 100 ms full-rate beacon interval, showing that the system can perform a complete collision prediction processing before it receives a next beacon.

Value of  $t_{reaction}$  is set to 0.83 seconds as stated in [19]. To get  $d_{brake}$ , for the sake of this evaluation we estimate an average  $a_{brake}$  value by referring to statistical data of different brake distances and replacing those values in formula  $a_{brake} = v^2 / (2d_{brake})$ . Therefore, according to  $\{v, d_{brake}\}$  values provided by the UK Highway Code [18],  $a_{brake}$  is calculated for speeds of 48, 80 and 112 km/h as 6.35, 6.5 and 6.45 m/s<sup>2</sup> respectively. All values are around 6.5 m/s<sup>2</sup> and therefore they are almost indifferent to speed. In this paper, we assume a normal road and pavement condition and consider  $a_{brake}$  value of 6.5 m/s<sup>2</sup> regardless of car make and car speed.

As mentioned before, collision avoidance systems work in a certain limited range ( $w_{max}$ ). For example, the safety brake system developed in [21] and pedestrian detection system being developed by authors of [10] have the range of 200 meters, and the V2P safety system proposed in [22] has the range of around 180 meters. In this paper, we also conclude a similar value according to (3) by replacing its parameters with their values drawn up earlier in this section. Assuming our system supports vehicle speeds up to  $v = 30$  m/s (108 km/h) and in order to prevent a worst case scenario of head-on collision where both road users are moving towards each other with such speed, we have  $w_{process\&brake} = 2(30 \times 0.06 + 30 \times 0.83 + 30^2 / (2 \times 6.5)) = 191.4$  m. Therefore, vehicles should receive an update beacon from each other at least at:  $w_{max} = w_{process\&brake} = 191.4$  m.

Having above values, Fig. 3 illustrates equation (2) with four vehicle speed values of 10, 20, 30 and 40 m/s (shown as km/h on the chart). As shown in this figure, the maximum beacon interval possible decreases with increasing vehicle speed. We use these four  $\{v, i_{max}\}$  pairs as sample inputs for our analysis in the rest of this paper.

In order to calculate battery life according to (5), we select Samsung Galaxy S3 as our sample smartphone which has battery capacity ( $C$ ) of 7.98 Wh (with 2100 mAh and 3.8 V). To have a better understanding of overhead caused by our safety system, we consider different power consumption values for  $P_0$ . We assume one rather weak energy consumption management of  $P_0 = 1.5$  W (battery lasting only about  $t_0 = 5$  hours with usual daily usage), another with an average energy consumption management of  $P_0 = 0.5$  W (a 2100 mAh battery similar to Samsung Galaxy SII but lasting about  $t_0 = 16$  hours with usual daily usage), and finally with a rather good energy consumption management of  $P_0 = 0.15$  W (a 2100 mAh battery similar to Samsung Galaxy SII but lasting about  $t_0 = 53$  hours (2 days and 5 hours) with usual daily usage).

Furthermore, to calculate  $P_{adaptive}$  (6), the  $t_{fullrate} / t_{lowrate}$  ratio can be illustrated using a probability chart. However, for the sake of our analysis in this paper, we assume a 24 hours (full day) time period and consider 25 discrete values ranging from 0/24 (all day in risk-free situation) to 24/0 (all day in risk-prone

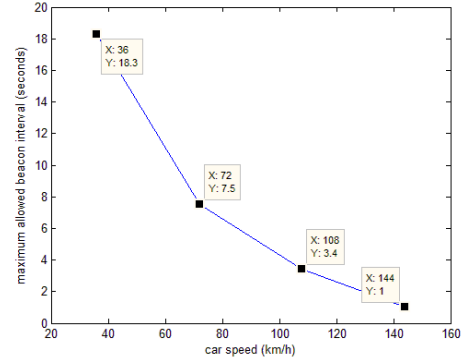


Fig. 3 Maximum beacon interval on smartphones according to vehicle speed.

situation). On the other hand, as explained in section III,  $P_{nonadaptive} = P_{fullrate}$ .

We use optimized LTE (with DRX) in our evaluations, which has tail = 0.1 second and data rate of 100 Mbps. We assume the amount of transferred data (beacon message size) to be 1000 bytes and therefore value of  $t_{transmit}$  is calculated as 0.00008 ( $t_{transmit} = \text{message-size} / \text{data-rate}$ ). Furthermore, values of  $P_{tail}$  and  $P_{transmit}$  are measured as 1.216 W and 1.52 W according to experiments performed in [23]. For  $P_{lowrate}$  (7),  $i_{low-rate} \geq 1$  and  $t_{idle} = i_{low-rate} - t_{transmit}$  is larger than the DRX tail, therefore  $t_{tail}$  is considered equal to DRX tail which is 0.1 s. As a result,  $P_{lowrate}$  in our evaluations is a variable which depends on the  $i_{low-rate}$ . For  $P_{fullrate}$  (8) however, because  $i_{full-rate} = 0.1$  s (100 ms) and  $t_{idle} = 0.09992$  s is smaller than the DRX tail, therefore  $t_{tail}$  is also considered equal to idle time (0.09992 s). As a result,  $P_{fullrate}$  is calculated as constant value of 1.216 W.

Having above values, we calculate overhead of both our adaptive method and non-adaptive method on smartphone battery life according to (5) and (9). Fig. 4 illustrates the results.

## V. ANALYSIS AND DISCUSSION

In this section, we analyze the evaluation results of section IV and discuss different factors affecting efficiency of our approach.

### A. Energy-efficiency of Different Smartphones

Comparing the three charts of Fig. 4, it is concluded that the overhead of our approach over smartphone battery life ( $t_{overhead-adaptive}$ ) has a direct correlation with the smartphone typical battery life ( $t_0$ ). For example, assume a pessimistic full-rate mode duration of 5 hours per each 24 hours. With the first smartphone which originally has only around 5 hours of battery life, the maximum overhead (with  $i_{low-rate} = 1$  s) is only around 20% and therefore our adaptive method is practical. Whereas, with the last smartphone which originally has more than 53 hours of battery life, the maximum overhead (with 1 second interval) gets as high as 70% and therefore our adaptive approach is not practical. However, overhead slope is also steeper in this case, resulting in more chances of saving battery if we can decrease the full-rate duration.

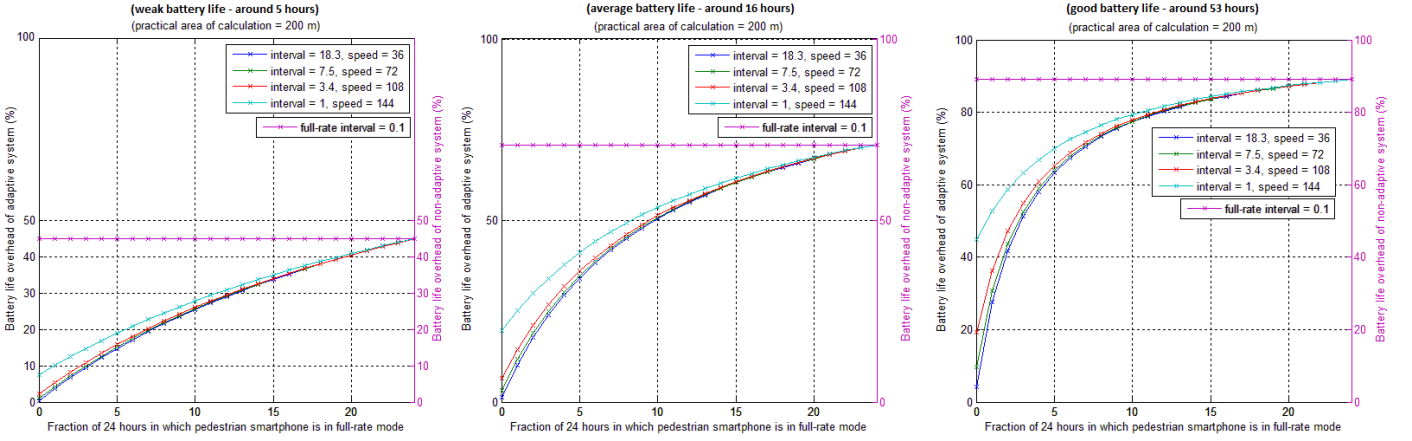


Fig. 4. Overhead of pedestrian safety system on battery life of pedestrian's smartphone.

### B. Urban Areas and Pedestrian Daily Mobility Pattern

More importantly, Fig. 4 shows that system performance in terms of energy-efficiency (battery life overhead) significantly depends on the fraction of time pedestrian spends in risky situations (and thus full-rate mode is active). This fraction of time itself is directly influenced by traffic conditions near pedestrians. As a result, energy-efficiency and battery life depend on several factors such as the city area where the pedestrian is located, traffic volume as well as mobility patterns of pedestrians moving from one urban area to another. For example, whether the pedestrian is located in the busy city center or in the suburbs makes a difference in system full-rate activity. A realistic simulation of daily vehicle and pedestrian mobility will give a better understanding of how often pedestrians are in risky situations, and thus a more precise estimation of energy-saving achieved via our method. This simulation is postponed to a future work, however in this section we perform initial study on how often and with which conditions it is possible to switch to the low-rate mode.

Firstly, spending 5 hours out of 24 hours in a risky scenario is a very pessimistic assumption for a typical daily life, considering that most of daily hours might be spent indoors or riding a transport means such as personal car and public transport. Secondly, by utilizing a smart context-detector, we can additionally take into account information such as pedestrian movement path and street maps to filter out more non-risky situations and thus reduce the full-rate fraction as much as possible. Based on above discussion, we assume that the time spent in risky situation (system being in full-rate mode) is less 1 hour for majority of pedestrians. In addition, we consider the typical speed limit in highways (e.g. 110 km/h) and choose the 3.4 seconds low-rate interval accordingly (not  $i_{low-rate} = 1$  required for  $v = 144$  km/h).

### C. Summary

As a result, for the three smartphones presented in Fig. 4, we get maximum battery life overhead of approximately 5%, 15% and 35% respectively, while overhead of a non-adaptive method (always full-rate) is approximately 45%, 70% and 90% regardless of the time spent in risky situations. Therefore it is

concluded that a non-adaptive system is not practical due to the short battery life. However, our adaptive method tackles this battery life problem and enables running pedestrian road-safety system on smartphones.

## VI. CONCLUSION

In this paper, we have proposed an adaptive multi-level approach for pedestrian road-safety which uses cellular technologies such as LTE as its main communication method and employs mainstream smartphones rather than dedicated hardware. Firstly, we concluded that in comparison to ad-hoc technologies (e.g. WiFi, IEEE 802.11p), cellular technology is a better fit for pedestrian safety applications in terms of reducing user adoption costs and reducing market penetration time. Secondly, in order to save smartphone battery life, we proposed an adaptive multi-level approach in which frequency and mode of V2P communication is adjusted depending on the collision risk. The collision risk level depends on several factors including pedestrians' location (e.g. city center, beside a highway or rural area), proximity to vehicles and movement direction. Based on our evaluation, this method considerably saves electrical energy compared to a non-adaptive method and thus makes the cellular-based pedestrian road-safety system practical.

As a future work, we are performing simulations based on realistic traffic data in order to get a more precise estimation of system scalability, energy efficiency and average user experience depending on urban area and daily mobility habits. In addition, in order to get a better understanding of system behavior, its communication latency and collision avoidance accuracy in practical scenarios, we are developing a V2P road-safety prototype based on our framework and using 3G and LTE methods. The results will be presented in a future work.

Another future work is to enhance our system so that even the low-rate beaconing is completely turned off when it is not needed at all. Such contexts include when the person is not moving at all, when pedestrian is not close to any roads, and when the smartphone is being charged indoors (i.e. not possible to move at all). This enhancement is achieved by utilizing smartphone features (e.g. sensors) to add a smart context-



detector to our system. This way, we can develop a more energy-efficient system with much less battery life overhead.

Finally, a more detailed energy consumption analysis should be performed to understand the correlation of system parameters such as beaconing frequency versus quality of service and energy consumption. Such analysis will help in designing a system with optimal architectural choices and arrangements.

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