Novel Channel Hopping Sequence Approaches to Rendezvous for VANETs

Samuel Montejo-Sánchez
Department of Electrical Engineering
University of Chile, Santiago, Chile
smontejo@ing.uchile.cl

Cesar Azurdia-Meza
Department of Electrical Engineering
University of Chile, Santiago, Chile
cazurdia@ing.uchile.cl

Sandy Bolufé
Department of Electrical Engineering
University of Chile, Santiago, Chile
sbolufe@ing.uchile.cl

Sandra Céspedes
Department of Electrical Engineering
University of Chile, Santiago, Chile
scespedes@ing.uchile.cl

Ismael Soto
Department of Electrical Engineering
University of Santiago, Santiago, Chile
ismael.soto@usach.cl

Richard Demo Souza
Department of Electrical Engineering
Federal University of Santa Catarina, Brazil
richard.demo@ufsc.br

***Abstract*—Vehicular *ad hoc* networks (VANETs) have emerged as a paradigm for sharing information among vehicles and infrastructure that has the potential to provide road safety and travellers comfort. The bandwidth limitation is one of the main challenges of this technology, however, the growing perspectives of applications demand more and more service channels. In this work we propose two novel channel hopping (CH) sequence approaches to rendezvous, in order to allow VANET applications to use unlicensed channels. Besides, practical implementation considerations to reduce the search space and to replace the busy channels are discussed. We evaluate the performance of the proposed strategies in the presence of users competing for the available channels. Our results indicate that with a suitable CH sequence it is possible to increase the number of useful channels for rendezvous and thus decrease the percentage of failed rendezvous.**

***Keywords*—*Channel hopping sequence, cognitive radio, rendezvous, vehicular ad hoc networks*.**

I. Introduction

At present time, the biggest problem regarding the increased use of private transport is the increasing number of fatalities that occur due to road accidents; the expense and related dangers have been recognized as a serious problem [1]. Traffic jams and road fatalities can be reduced by providing proper information about the road conditions and its surrounding environment to vehicle drivers in a secure way. VANETs are the most likely approach to provide safety information and other infotainment applications to both drivers and passengers [2]. This new paradigm of sharing information among vehicles and infrastructure will enable a variety of applications for safety, traffic efficiency, driver assistance, infotainment, and urban sensing, to be incorporated into modern vehicle designs [3].

A Vehicular *ad hoc* network (VANET) is a special case of a mobile *ad hoc* network (MANET), but differ by its architecture, characteristics, challenges and applications. The goal of a VANET architecture is to allow the communication among on board units (OBUs) of nearby vehicles and between these and fixed roadside equipments, roadside units (RSUs); leading to the following three possibilities [3]: vehicle to vehicle (V2V) *ad hoc* network; vehicle to infrastructure (V2I) network; or hybrid architecture (combines both V2V and V2I). The unique characteristics of VANET include [1]: predictable mobility, no power constraints, high computational ability, large scale network, variable network density, and rapid changes in network topology. Thus it is vital to specify the main important challenges in VANET [1]: signal fading, bandwidth limitations, connectivity, and small effective diameter. Given the challenges and characteristics of VANETs, some future perspectives should be considered to design efficient communication approaches [3]: highly heterogeneous vehicular networks, data management and storage, cooperation with other networks, security and privacy, network fragmentation, and disruptive tolerant communications.

Defined specifically to VANETs, the DSRC (Dedicated Short Range Communication) system, known as IEEE 802.11p WAVE (Wireless Access in Vehicular Environment), is a short to medium range communication technology that operates in the 5.9 GHz band for the use of public safety and private applications [4]. The frequency band is divided into six service channels (SCH) and one control channel (CCH) with equal bandwidth of 10 MHz each one. Each transceiver interested in offering or consuming proximity services must therefore switch between CCH and SCH channels. Synchronous channel switching is required by all stations to be simultaneously on the CCH for safety-related messages, which leads to a complex and inefficient usage of the overall channel capacity. A proposal by the ETSI [5] is to let CCH and SCH be independently operated by two transceivers, for which synchronous channel switching is no longer required.

Although resource allocations on the CCH reserved for safety-related applications have been well investigated, efficient usage of the others SCHs has attracted less attention. In [6], the authors propose a flexible mechanism based on cognitive principles to let rendezvous, between service providers and users, on a given service channel without relying on the CCH. Providers and users dynamically alternate between a service announcement channel (SACH) phase to receive

978-1-5386-3123-2/17/$31.00 ©2017 IEEE

service announcements and a service phase on other SCH to receive or offer services. However, this proposal has a reduced service capacity and an inefficient performance in a high density environment. Besides, the growing perspectives of VANET applications demand more and more service channels. Therefore, in few years the DSRC channels could be not enough and other alternatives should be used, such as TV white space bands and cognitive methods to find an available channel and establish a communication link, as in [7], [8].

Two cognitive users can communicate when both are in one of the available channels and exchange the required signaling information. The process of two or more users to meet on a common channel is referred to as rendezvous, and to achieve it two strategies can be employed [9]: common control channel (CCC); or channel hopping (CH) sequences. In CCC, the users choose the same channel to exchange signaling information, as in [6]. Although being the simplest variant, its main drawback is that this constitutes a single point of failure, experiencing congestion when the number of users increases. In CH, each node employs a hopping sequence that guarantees rendezvous in one of the available channels. This process is referred to as blind rendezvous. Recently in [10], the authors proposed a short-sequence-based (SSB) strategy for rendezvous in cognitive radio networks, that works under the symmetric and asymmetric models, and presented an analysis of the benefits of short periodic channel hopping sequences in the rendezvous process. However, the design of SSB has not taken into account the presence on the stage of other cognitive users, who compete to reach an available channel to establish their own communication. So, this strategy may not be the ideal one for VANET scenarios, mainly in urban environments with high traffic density.

In this work we propose two novel channel hopping sequence approaches to rendezvous for VANETs, both inspired in [10], one of them adapted to VANET environments and the other one oriented to outperform the performance of SSB in terms of time to rendezvous (TTR). Our proposal aims to favor VANET applications so that they can use unlicensed channels, guaranteeing the rendezvous process and investigating the performance of the proposed strategies in the presence of other users competing for the available channels.

The rest of this paper is organized as follows. Section II presents the system model, while in Section III two novel channel hopping sequence approaches to rendezvous for VANETs and other practical considerations are described. In Section IV some numerical results are discussed, while Section V concludes the paper.

II. System Model

A. Preliminaries

In this work we consider a VANET with OBUs operating as cognitive users that posses two tranceivers; one of them for attending road safety applications in the CCH channel, whereas the other transceiver is used for other services that could be offered in available channels of the unlicensed spectrum. It is assumed a symmetrical model in which the total users are divided in subsets, and to each subset of users corresponds a subset of n channels to communicate. The channels within each subset are identified distinctively, and in this work will be identified as $\{1, 2, ..., n\}$, where N is the total of available channels; therefore, N/n is the amount of available user subsets and assigned channels subsets. This is because a paradox is established between having the largest number of available channels, to minimize the probability of being all occupied by the services offered by other users, and to reduce the search space to decrease the TTR. It is therefore necessary to put into practice an intelligent channel allocation strategy that allows any user to know the subset of channels in which another specific user can be found by performing the preset CH sequence.

It is assumed that to perform the rendezvous process time is divided into slots of duration 2τ, being τ the time required to guarantee the exchange of information of signalization. This fact avoids the dependence of timing edges between users, by ensuring that the overlap between two time slots is sufficient to complete the rendezvous [11]. However, for reasons of simplicity from this point on we will refer to the different time slots with discrete values. So if a rendezvous is specified during the time slot i-th, then TTR $= i - 1$.

Faced with the lack of evaluation in [10] of the presence of multiple users, as the authors consider only the presence of the pair involved in the rendezvous, we propose in this paper to evaluate the performance of our proposals and the SSB strategy in a scenario where users compete simultaneously to communicate through the available extra channels in a scenario in which all SCH channels are already busy.

B. Short-sequence-based (SSB) Strategy

The sequence in SSB is based on discrete segment which is arranged from the set of n available channels. The users start the rendezvous process from the one extreme 1 to the other extreme n. Once reaching the end of the segment, the users hop to the opposite path (from n to 1). In a continuous segment, any two users could meet before the one who started later reaches the extreme of the segment. However, since the users jump to discrete points (channels) of the segment, they transpose their positions without rendezvous in some cases. Thus, to avoid this problem, once a user returns to the origin of the sequence, it remains there during one time slot, so that in the next rendezvous attempt they will certainly meet.

In Table I the above procedure is illustrated for $n = 3$. The first column the rows represent the possible channel hopping sequences. In the penultimate column the phase shift, d_o, of these sequences is shown, which is calculated as the shift from the beginning of the original search sequence (which has $d_o = 0$). In the last column the TTR is represented, which is equivalent to the first encounter between the represented sequence and the search sequence (highlighted in bold in each sequence). From the data given by Table I, it can also be determined that for SBB with $n = 3$, the expected TTR (ETTR) is 1.6 and the maximum TTR (MTTR) is 4, which are important metrics commonly used to evaluate these strategies.

TABLE I
SSB STRATEGY

Sequences					d_o	TTR
1	2	3	2	1	0	0
2	3	2	1	**1**	1	4
3	**2**	1	1	2	2	1
2	1	1	**2**	3	3	3
1	1	2	3	2	4	0

From a simple inspection of the SSB strategy we can identify two weaknesses:

- When nothing interferes with the rendezvous process (ideal conditions or ideal case), the rendezvous never occurs in the n-th channel. So in reality only the $(n-1)$ previous channels are used.
- Of the $(n-1)$ used channels, the highest percentage of use is the first, surpassing $\frac{100}{2n-1}$ to the rest of the channels, that is 20% for $n=3$ and 11% for $n=5$.

III. NOVEL CHANNEL HOPPING SEQUENCE STRATEGIES

A. Fast Short-sequence-based (F-SSB) Strategy

The second SSB weakness can be conveniently used to decrease the ETTR. If we vary the order of the search sequence, by making the rendezvous in the most used channel occur in the first positions $\{1,1,2,...,n,...,2\}$, then the resulting ETTR will decrease accordingly. From Table II we can determine that the ETTR value for F-SSB, our novel proposal, with $n=3$ is 1.4, whereas as expected the MTTR value remained equal to 4 as in SSB. By a mathematical analysis similar to the one detailed in [10] it is possible to deduce that the ETTR decreases in $\frac{1}{2n-1}$ time slots, which can be verified in Table IV, where the expressions give ETTR and MTTR in F-SSB for the ideal case.

TABLE II
F-SSB STRATEGY

Sequences					d_o	TTR
1	1	2	3	2	0	0
1	2	3	2	1	1	0
2	3	**2**	1	1	2	2
3	2	1	1	**2**	3	4
2	**1**	1	2	3	4	1

B. Extended Short-sequence-based (E-SSB) Strategy

The first weakness of SSB is most damaging because by decreasing the number of useful channels for rendezvous for the same number of users increases the probability of performing rendezvous on a channel that has already been occupied by another pair of users. Therefore, in this sense we set ourselves the task of extending the SSB sequence, increasing the presence of the n-th channel to ensure that it also produces rendezvous. The extended sequence for the E-SSB, our second proposal, is $\{1,...,n,n,n,...,1\}$, by means of which rendezvous can be performed in the n channels and that the difference in utilization between the most used channel, in this case the n-th channel, and the rest of the channels is $\frac{100}{2n+1}$, which is a 14% for $n=3$ and 9% for $n=5$.

TABLE III
E-SSB STRATEGY

Sequences							d_o	TTR
1	2	3	3	3	2	1	0	0
2	3	**3**	3	2	1	1	1	2
3	3	**3**	2	1	1	2	2	2
3	3	2	1	1	**2**	3	3	5
3	**2**	1	1	2	3	3	4	1
2	1	1	2	**3**	3	3	5	4
1	1	2	3	3	3	2	6	0

The cost to pay for this strategy is that the ETTR and the MTTR increase with respect to the other strategies. From Table III we can determine that the ETTR value for E-SSB with $n=3$ is 2 and the MTTR is equal to 5. By means of a mathematical analysis, it can be deduced that the ETTR for E-SSB increases with respect to the SSB in $\frac{n-1}{2n-1}$ time slots, whereas the MTTR grows in one time slot. The above data can be verified in Table IV, where the expressions give ETTR and MTTR for an ideal case E-SSB . In addition to the traditional metrics, we have denoted the channels to rendezvous (CTR), to refer to the number of useful channels for rendezvous.

TABLE IV
PERFORMANCE METRICS

Strategy	ETTR	MTTR	CTR
SSB	$\frac{2(n-1)^2}{2n-1}$	$2n-2$	$n-1$
F-SSB	$\frac{2(n-1)^2-1}{2n-1}$	$2n-2$	$n-1$
E-SSB	$n-1$	$2n-1$	n

C. Practical Implementation Considerations

In addition to the existing CH sequences strategies, some practical considerations regarding implementation should be addressed. These practical considerations should answer the following questions: 1) How to assign the channels by subsets to shorten the search space, using an effective and distributed mechanism? 2) What to do when the rendezvous happens on a channel that is already being used by another pair of users? The following approaches address possible solutions to these problems.

1) The channels allocation is intended to create N/n subsets of size n from the N available channels, such that N is greater than n . This mechanism must be done in a distributed way, allowing any user to determine the set of channels assigned to the user with which it is intended to communicate. To this end we will exploit the periodic transmission of beacons [7], [12]. We denote T_B as the beacon period and divide this period into N/n time segments with duration $\frac{n}{N}T_B$. Then, each user will be performing the preset CH sequence in the channels corresponding to the time elapsed since the last beacon transmission. This can be expressed mathematically as follows, where t is the time elapsed since

the last beacon transmission according to the segment $\left(\frac{(x-1)nT_B}{N}, \frac{xnT_B}{N}\right)$ and then the user is self-assigned to the subset of channels $[(x-1)n+1, xn]$, it is such that $x \in \{1, 2, ..., N/n\}$. Since each beacon information is stored by each user in its neighbor table, then each user first polling their neighbor table will be able to determine the subset of channels in which a specific user is developing the channel hopping sequence.

2) Although every time a rendezvous process is preceded by a spectrum sensing phase to determine which channels are actually available, it is still possible for a pair of users to be on a channel recently occupied by another pair of users that are assigned to the same subset simultaneously. As our proposal considers that each subset of users (vehicles) is made up of more than two users; therefore, it is possible that more than two users will start the rendezvous process in the same channels subset. In view of this situation, and to avoid interfering with the pair that first arrived at the channel, users should replace that channel with another available channel. Various replacement strategies can be used, one of them for example being to randomly select any of the other available channels. However, in the present work we have proposed replacing the reserved channel by the last of the available channels, to favor the use of the same in the SSB and F-SSB strategies, reducing the probability of another failed rendezvous.

IV. Numerical Results

In this section we present some numerical results in order to evaluate the performance of SSB, F-SSB and E-SSB. All computer simulations were carried out using the Monte-Carlo method and Matlab. For the sake of simplicity, and as a first approximation to the phenomenon, we will focus the analysis on four users $\mathcal{U}_i$, $i \in \{1, 2, 3, 4\}$. The evaluation is based on a case where $\mathcal{U}_1$ wants to communicate with $\mathcal{U}_2$ and simultaneously $\mathcal{U}_3$ wants to communicate with $\mathcal{U}_4$. In this case, the rendezvous between $\mathcal{U}_1$ and $\mathcal{U}_2$ is not valid once it encounters a common channel previously occupied by $\mathcal{U}_3$ and $\mathcal{U}_4$. Several performance metrics will be evaluated in these systems, such as ETTR and MTTR. In addition, the interruptions in the rendezvous process will be investigated too.

A. Without Competition

Regarding the number of users, ideal conditions for the rendezvous process would be that users $\mathcal{U}_2$ and $\mathcal{U}_4$ are not in the same subset of channels. This fact makes rendezvous processes occur in different search spaces, and therefore do not interfere with each other.

Fig. 1 and Fig. 2 show the maximum TTR and average TTR under ideal conditions, respectively. In both figures the high correspondence between the analytical results and the simulations is observed, evidencing the applicability of the expressions deduced and shown in the Table IV. Also, it is corroborated that the TTR increases when the number of available channels increases. As expected in both metrics, the worst performance corresponds to E-SSB scheme, because it uses a sequence of greater size. The MTTR achieved with E-SSB is one time slot larger than when using SSB and F-SSB, see Fig. 1 and Table IV. For the ETTR (see Fig. 2), a increase of the ETTR never is greater than τ. Further, and as expected with respect to ETTR, the F-SSB strategy achieves better results than SSB.

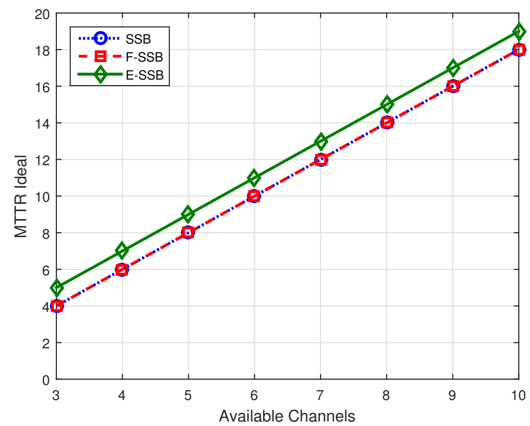

Fig. 1. Maximum TTR without Competition

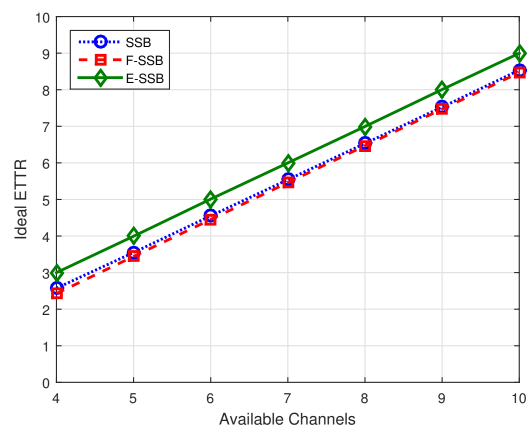

Fig. 2. Expected TTR without Competition

B. With Competition

However, when both pairs of users compete to reach a channel within the same subset of channels, what is case when $\mathcal{U}_2$ and $\mathcal{U}_4$ coincide in the same subset of n channels, the performance of the strategies change significantly. Fig. 3 illustrates how in the presence of another pair of users competing for the same channels, the average TTR is very similar for all three strategies, being even slightly lower for the E-SSB. The reason for this improvement in the ETTR of E-SSB is because the average TTR after failed attempts is lower for the E-SSB strategy than for the other strategies, as shown in Fig. 4. This is mainly because E-SSB has one more useful channel

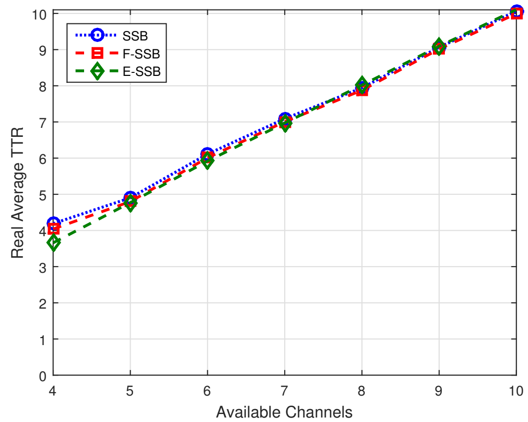

Fig. 3. Average TTR with Competition

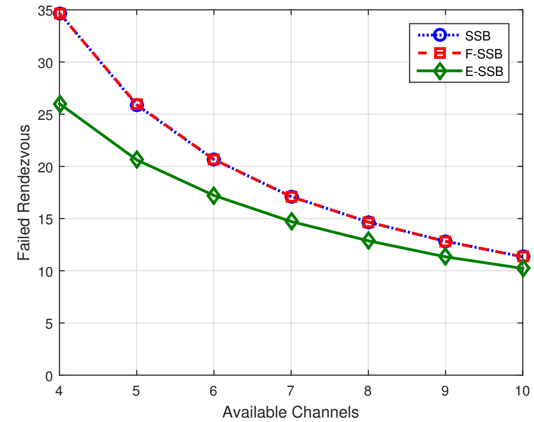

Fig. 5. Percentage of Failed Rendezvous Attempts

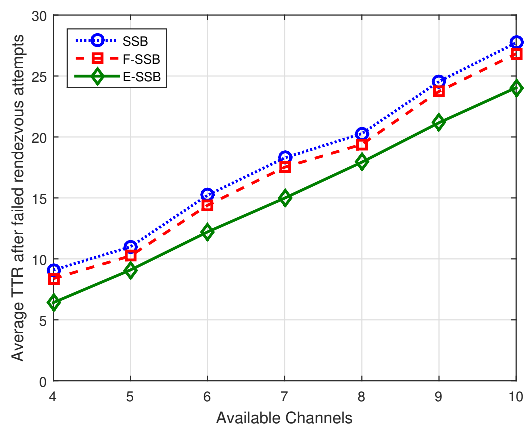

Fig. 4. Average TTR after Failed Rendezvous Attempts

for rendezvous (n-th channel), decreasing the probability of coincidences when competing for the same channels. This can be verified in Fig. 5, where for $n = 4$, the failed rendezvous attempts are 8% less when using E-SSB than when using SSB or F-SSB. This advantage becomes smaller as the number of available channels increases, but it should be pointed out that with this increase the average TTR also increases.

V. Conclusion

In this paper we proposed two novel channel hopping (CH) sequence approaches to rendezvous. The numerical results evidenced the usefulness of our proposals. F-SSB outperforms the others rendezvous strategies in terms of TTR, while E-SSB allows to increase the number of useful channels for rendezvous and thus decreases the percentage of failed rendezvous. Besides, the practical implementation considerations favor the applicability of these approaches in VANET scenarios. In the near future we intend to investigate the performance of the proposed strategies under the presence of more simultaneous users, considering also the wireless link impairments in the signaling information exchange.

Acknowledgment

The authors acknowledge the financial support of FONDECYT Postdoctoral Grant No. 3170021, as well as project ERANET-LAC ELAC2015/T10-0761.

References

[1] S. Al-Sultan, M. M. Al-Doori, A. H. Al-Bayatti, and H. Zedan, "A Comprehensive Survey on Vehicular Ad Hoc Network," *Journal of Network and Computer Applications*, vol. 37, pp. 380–392, 2014.

[2] M. Azees, P. Vijayakumar, and L. J. Deborah, "Comprehensive Survey on Security Services in Vehicular Ad Hoc Networks," *IET Intelligent Transport Systems*, vol. 10, no. 6, pp. 379–388, 2016.

[3] F. Cunha, L. Villas, A. Boukerche, G. Maia, A. Viana, R. A. Mini, and A. A. Loureiro, "Data Communication in VANETs: Protocols, Applications and Challenges," *Ad Hoc Networks*, vol. 44, pp. 90–103, 2016.

[4] J. B. Kenney, "Dedicated Short-range Communications (DSRC) Standards in the United States," *Proceedings of the IEEE*, vol. 99, no. 7, pp. 1162–1182, 2011.

[5] *Intelligent Transport Systems (ITS); Harmonized Channel Specifications for Intelligent Transport Systems Operating in the 5 GHz Frequency Band*, 2012.

[6] L. De Martini and J. Harri, "Short Paper: Design and Evaluation of a Multi-Channel Mechanism for Vehicular Service Management at 5.9GHz," in *IEEE Vehicular Networking Conference (VNC)*. IEEE, 2013, pp. 178–181.

[7] J.-H. Lim, W. Kim, K. Naito, J.-H. Yun, D. Cabric, and M. Gerla, "Interplay Between TVWS and DSRC: Optimal Strategy for Safety Message Dissemination in VANET," *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 11, pp. 2117–2133, 2014.

[8] A. Arteaga, S. Céspedes, and C. Azurdia, "Spectrum Sensing for Vehicular Dynamic Spectrum Access," in *Proceedings of the II Spring School on Networks*, vol. 1727. ceur-ws.org, 2016, pp. 8–13.

[9] Z. Htike, C. S. Hong, and S. Lee, "The Life Cycle of the Rendezvous Problem of Cognitive Radio Ad Hoc Networks: a Survey," *Journal of Computing Science and Engineering*, vol. 7, no. 2, pp. 81–88, 2013.

[10] V. A. Reguera, E. O. Guerra, R. D. Souza, E. M. Fernandez, and G. Brante, "Short Channel Hopping Sequence Approach to Rendezvous for Cognitive Networks," *IEEE Communications Letters*, vol. 18, no. 2, pp. 289–292, 2014.

[11] D. Yang, J. Shin, and C. Kim, "Deterministic Rendezvous Scheme in Multichannel Access Networks," *IEEE Electronics Letters*, vol. 46, no. 20, pp. 1402–1404, 2010.

[12] J. Joo, R. Woo, and D. S. Han, "An Enhanced Broadcasting Scheme for IEEE 802.11p According to Lane Traffic Density," in *20th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*. IEEE, 2012, pp. 1–4.