Link Activation with Parallel Interference Cancellation in Multi-hop VANET

Meysam Azizian, Soumaya Cherkaoui and Abdelhakim Senhaji Hafid†
Department of Electrical and Computer Engineering, Université de Sherbrooke, Canada
Email: {meysam.azizian, soumaya.cherkaoui}@usherbrooke.ca
†Department of Computer Science and Operations Research, University of Montreal, Canada
†Euromed University, Fes, Morocco
Email: ahafid@iro.umontreal.ca, a.senhaji@ueuromed.org

Abstract— **In this paper, we propose parallel interference cancellation (PIC) for link activation in VANETs. Link activation (LA) stands for activating a set of communication links which can transmit simultaneously without transmission collisions. We consider multi-hop VANET scenarios where vehicles are clustered using d-hop clustering algorithms such as proposed in [1]. We model the interference cancellation as a mixed integer programming (MIP) optimization problem where wireless link conditions are analyzed. The proposed parallel interference cancellation method can be used for scheduling of transmissions and resource sharing inside the constructed clusters. Simulations were performed for different scenarios to show the performance of the improved LA.**

Keywords—Contention-free; vehicular ad-hoc networks; optimization; TDMA; interference cancellation

I. Introduction

In VANETs, vehicles communicate with each other so as to enable services ranging from traffic management, to accident avoidance and resource sharing [2]. Dense and highly dynamic network topologies are characteristics of VANETs which make routing functions and bandwidth reservations difficult. Clustering of vehicles, which groups vehicles in a geographic area for networking purposes, has been proposed as a way to provide scalability for VANETs. Clustering can improve communication efficiency by facilitating network management [3].

LA means activating a set of transmission links which can transmit concurrently without collisions. LA has a key role in transmission scheduling, and cross layer design optimization problems. It is also important for other purposes such as rate adaptation, and routing in VANETs. For a link to be activated, a pre-defined Signal-to-Interference-and-Noise Ratio (SINR) should be satisfied at the receiver. In highly dense vehicular scenarios, it is difficult for all links to be activated as transmissions on different links cause interferences to others. LA using a single user decoder (SUD) has been recently studied in VANETs [4]. However, IC cancellations effect on LA which has been proposed for general wireless ad-hoc networks is a new subject for VANET [5].

In this paper, we use multi-user decoders (MUDs) which make it possible to remove strong interferences. Therefore, more links can be activated simultaneously. Interferences from other communication links are coded signals which can be decoded and removed from the signal of interest. To cancel interferences, we use PIC which provides the possibility of cancelling the strong interferences in one stage. Each receiver with the capability of MUD plays the role of intended receiver for some signal of interest. All other interfering signals get analyzed carefully to see if they can be decoded and subsequently removed from the signal of interest. An interference signal should be strong enough compared to other transmissions containing the signal of interest to be decoded. In other words, "interference-to-signal-of-interest-and-noise" ratio should satisfy the SINR of the interference signal. With a MUD approach, having more powerful interferences is advantageous. This helps close-distanced transmission links to be activated without interfering with each other.

MUD receiver's implementation is an ongoing research topic [6] and technically implementing interference cancellation is possible. Transmitters in MUD should be synchronized in time and frequency. Receivers should also be able to estimate the channels between themselves and all interfering signals. In this work, we assume MUD is can be perfectly implemented. We assign a non-negative weight to each link, and the objective is to find the maximum total of weights. For this purpose, we model the LA problem in VANETs a mixed integer programming optimization problem.

The rest of paper is organized as follows. Section 2 introduces the system model. Section 3 presents the notions used throughout the paper. Section 4 describes interference cancellation, and the parallel interference cancellation proposed for LA. Section 5 evaluates our proposed scheme through numerical methods. The paper concludes with section 5.

II. System Model

In this work, we assume multi-hop VANET scenarios where vehicles are clustered using a clustering algorithms, such as the algorithms in [1] or [7]. When vehicles are clustered, cluster members (CMs) have a determined route, comprised of several links (called "determined communication links", DCL), to their cluster heads (CHs). We consider the case where CMs are interested in sending data to their CHs. Therefore, the DCL links are links of interest for us and other links are considered as interferences, as shown in Fig.1.

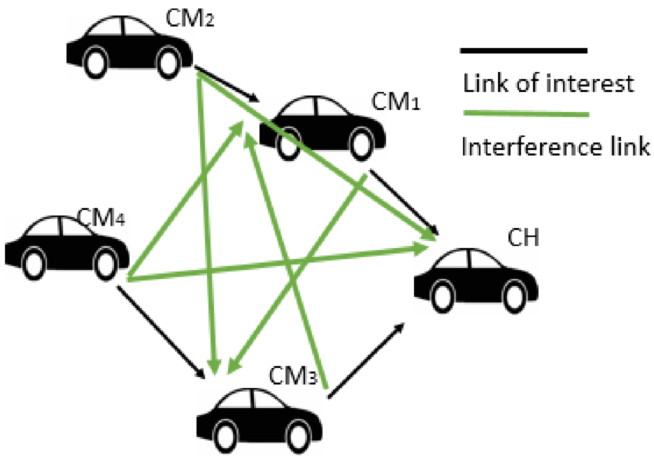

Fig.1. System Model.

In this work we propose a parallel interference cancellation algorithm which cancels strong interfering signals and improve a LA performance. LA means activating (letting them transmit) a set of links (links of interest) which can work simultaneously without interfering with each other. We assume that receivers on each vehicle (CM and CH) are capable of decoding more than one signal, i.e. the signal of interest and interfering signals. We also assume that receivers have decoding information of interfering signals. Therefore, receivers can decode the strong interferences and cancel them. Here, each vehicle needs to send the information of the received powers from the neighbouring nodes (signal of interest and interfering signals) to its CH. CH will have the global knowledge of the CMs in its cluster and their receiver's capability. It will decide to active the maximum number of links (links of interest), based on the PIC algorithm presented in section IV.

For the purpose of transmission scheduling (which is out of scope of this paper) CH must decide on activating different sets of communication links in different periods of time, to make a contention free transmission scheduling mechanism [4].

III. Notations

In the following, the terms vehicle and node are used interchangeably. VANET topology is modelled by a set of nodes $V, v \in V$ and a set of links E, $e \in E$. The originating node of link e, $a(e)$, is the transmitter and the terminating node of link *e*, $b(e)$, is the receiver node. $e = vw$, $v, w \in V$ represents a link between node v and w and $a(e) = v, b(e) = w$. We assume that if $vw \in E$, then link e'=wv will be the opposite of link *vw*. The set of links outgoing from/incoming to node v are denoted by $\delta^+(v)$and $\delta^-(v)$ respectively, and the set of all the links incident to node v is defined as $\delta(v) = \delta^+(v) \cup \delta^-(v)$.

We assume that p_{vw} is the transmitting power from node *v* to node *w* (we can also represent it in dBm scale with $\hat{p}_{vw}$). A communication link can transmit if it satisfies the signal to noise ratio (SNR) constraint [4]:

$$\text{SNR: } \frac{p_{vw}}{N} = \Gamma' \text{ , SNR} \geq \gamma \text{ ,} \tag{1}$$

Where γ is the SNR threshold and N is the noise power density.

In wireless networks, interference exists from various devices. For every link to be able to transmit, we define a new formula for the signal to interference noise ratio (SINR) as follows:

$$\text{SINR: } \Gamma = \frac{p_{vw}}{N + \sum_{a \in A \setminus \{v\}} p_{aw}} = \frac{p_{vw}}{N + I_{vw}} \text{ ,} \tag{2}$$

Where A is a set of active nodes, $A \subseteq V$, and I_{vw} is the interference sum which is received from other transmitting nodes. For link *vw* to be active, we should have $\text{SINR} \geq \gamma$.

IV. Inferference Cancellation

MUD and more specifically interference cancellation (IC) stem from fundamental studies on so-called interference channels [5], which precisely model the physical-layer interactions of wireless transmissions. With regard to IC, interferences are categorized either as low and thus can be considered as additive noise, either they are categorized as powerful so can be decoded and removed from the signal of interest.

The received signal at each receiver can be represented as *X=S+I+N*, where *S* is a signal of interest with power p_s and encoded rate R_S, I is interference with power p_I and encoded rate R_I, and *N* is receiver noise with power n.

In our work, we consider that an interference is powerful enough to be decoded (using MUD), when the condition below is satisfied:

$$\log_2\left(1 + \frac{p_I}{p_s + n}\right) \geq R_I \Leftrightarrow \frac{p_I}{p_s + n} \geq \gamma_I, \quad \gamma_I = 2^{R_I} - 1 \tag{3}$$

If the condition in Eq. (3) holds (the interference-to-other-noise-ratio is at least γ_I), I can be decoded and then removed from the received signal X, as shown below, where the SNR of the signal of interest S is examined (to see if it can be decoded):

$$log_2\left(1 + \frac{p_s}{n}\right) \geq R_s \Leftrightarrow \frac{p_s}{n} \geq \gamma_s, \quad (\gamma_s = 2^{R_s} - 1) \tag{4}$$

Where γ_s, is SINR threshold for decoding the signal of interest S.

When an interference is not powerful enough and condition in Eq. (3) cannot be satisfied, signal S should satisfy the condition in Eq. (5) to be decoded, where the interference is considered as additive noise in the denominator:

$$\frac{p_s}{n+p_I} \geq \gamma_s. \quad (5)$$

Although in the Eq. (3)-Eq. (5) ,we consider only one interfering signal, they can be extended to several interfering signals.

A. Parallel Interference Cancellation (PIC)

We use PIC to perform interference cancellation simultaneously by every receiver in a vehicular cluster. In PIC, when an interfering link is considered for cancellation at a vehicular node, other transmissions get treated as interference, no matter whether they are also being examined for cancellation or not.

Formulations for LA using PIC are described in this section. The correspondence MIP is also given afterward.

$$max \sum_e L_e \quad ,e \in \varepsilon \quad (6)$$

Equation (6) is the objective function which maximizes the total number of active links. To each link *e*, a variable L_e is assigned which specifies whether this link (e) is active or not.

The interference from node *a*(*f*) to node *b*(*e*) can be cancelled by node *b*(*e*) if the power of such interference is strong enough to full fill the inequality:

$$\frac{p_{a(f)b(e)}}{N + \sum_{g \in A\setminus\{f\}} \quad p_{a(g)b(e)}} \geq \gamma_f, \quad (7)$$
$$e \in A, f \in c_e$$

In (7), $p_{a(f)b(e)}$ is the received power at node *b* of link *e*, when a node *a* of link *f* is transmitting towards it. *A* is active link set, $A \in \varepsilon$ and $c_e \subseteq A \setminus\{e\}$ is the cancelled transmission for each $e \in A$. $\sum_{g \in A\setminus\{f\}} \quad p_{a(g)b(e)}$ is received power at node b of link e from all other active nodes excluding *f* . As shown in (7), the strong interference can be considered as better than weak interference. Weak interference might not be possible to get decoded, as the condition might not be satisfied.

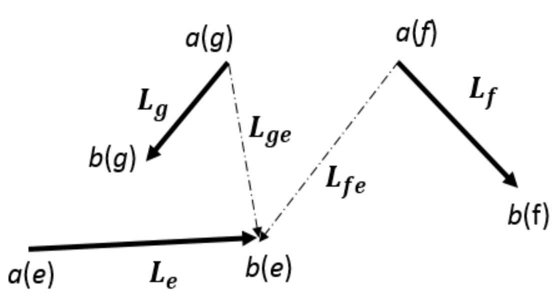

Fig. 2. Parallel interference cancellation

Link *e* can be activated when SINR ratio of link e is higher than or equal to a specific threshold defined for that link:

$$\frac{p_{a(e)b(e)}}{N+\sum_{f \in A[\{e\} \cup c_e]} \quad p_{a(f)b(e)}} \geq \gamma_e \quad (8)$$
$$,e \in A$$

In (8), $p_{a(e)b(e)}$ is the received power at node *b* of link *e*, when node *a* of link *e* is transmitting towards it. In the denominator of (8), the strong interference caused by transmissions is removed [in set Ce].

For better understating, the procedure of interference cancellation with using PIC is shown in Fig.2.

We present a MIP optimization model for the proposed LA based on PIC, as follows:

$$L_{fe} = \begin{cases} 1 \\ 0 \end{cases} e \in \varepsilon, f \in \varepsilon \quad (9)$$

$$L_e = \{0,1\} , e \in A \quad (10)$$

In (9), L_{fe} is a binary variable. Variable L_{fe} is 1 if the receiver of link e decodes and cancels the interference from link *f* and 0 otherwise. In (10), L_e is also a binary variable. 1 means that link e is active and 0 otherwise. The link *e* is active when the received SINR at the receiver of link *e* can pass the minimum threshold (requirement).

Equation (11) is objective function which maximizes the total number of active links:

$$\max \sum_e L_e \quad ,e \in \varepsilon \quad (11)$$

Eq. 11 is subjected to various constraints (Equations (12), (13), (14), (15) and (17)).

The node can either transmit or receive in an instant time. Therefore, only one link can be active at each node:

$$\sum_{e \in \delta(v)} L_e \leq 1 , v \in V \quad (12)$$

Link fe y_{fe} can be cancelled only when link e is active (interference link fe is considered only when the link which is interfered (e) is active):

$$L_{fe} \leq L_e, e \in \varepsilon, f \in \varepsilon, f \neq e \quad (13)$$

Link fe y_{fe} can be cancelled only when link *f* is active (interference link fe is considered only when the interfering link is active *f*) :

$$L_{fe} \leq l_f, e \in \varepsilon, f \in \varepsilon, f \neq e \quad (14)$$

The signal of interest must pass the formulated condition in Eq. 15, to be decoded. The condition formulates the SINR requirements for the signal of interest, where IC effect is considered in SINR ratio.

$$\frac{p_{a(e)b(e)} + M_e(1 - L_e)}{N + \sum_{f \in \varepsilon \setminus \{e\}} p_{a(f)b(e)}(L_f - L_{fe})} \geq \gamma_e \qquad (15)$$
$$, \ e \in \varepsilon$$

In (15), link fe is subtracted from denominator$(L_f - L_{fe})$, when L_{fe} is equal to 1 (can satisfy Eq. 17). Therefore, the interference from link f is removed and SINR for the signal of interest is strong er. We use M_e to pass the condition (Eq.15), when L_e is zero, as M_e has a big value. Therefore, when L_e equals to 0, the condition is passed and when we L_e is equal 1, the condition is considered.

M_e is large enough and can be calculated as below:

$$M_e = \sum_{f \neq e} p_{a(f)b(e)} \gamma_e + N\gamma_e - p_{a(e)b(e)} \quad e \in \varepsilon \qquad (16)$$

For the purpose of interference cancellation and checking the strength of link fe for decoding, the condition below should be satisfied (Eq.17). This condition (interference to other signals and noise ratio) has the received power of the interfering link f in the numerator and the other received signals (including signal of interest) in the denominator.

$$\frac{p_{a(f)b(e)} + M_{fe}\left(1 - L_{fe}\right)}{N + \sum_{g \in \varepsilon \setminus \{f\}} p_{a(g)b(e)}(L_e - L_{fe})} \geq \gamma_f \qquad (17)$$
$$e, f \in \varepsilon, f \neq e$$

In (17), for the receiver of link e to cancel the interference of link f, the receiver of e acts as if it was the receiver of f. The interference ratio must satisfy the SINR threshold of signal f to be decoded .In (17), placing L_{fe} to be zero is always feasible. When $L_{fe}$is zero (link L_{fe} is not possible to be decoded), the constraint (17) is always satisfied and there will be no effect on the objective, as M_{fe} is large enough.

M_{fe} can be calculated as below:

$$M_{fe} = \sum_{g \neq e} p_{a(g)b(e)} \gamma_f + N\gamma_f - p_{a(f)b(e)} \qquad (18)$$
$$e, f \in \varepsilon, f \neq e$$

V. Numerical results

In this section, we present the simulation results for the proposed LA where PIC is applied. Here, our proposed LA is compared to LA proposed in [4]. In [4], LA is performed using SUD receivers and interfering signals are considered as noise. We assume every vehicle's receiver is capable of decoding more than one signal, signal of interest and the strong interfering signals. Therefore, receivers act as MUDs.

.

Table 1 Simulation parameters

Parameter	Value
Modulation	BPSK
Coding rate	1/2
Raw bitrate	6 Mbps
Propagation model	Log-distance path loss model
Transmitting Power	20 dBm
Noise power density	-131 dBm
Communication range	274m (max)
Bandwidth	10MHz
Path loss exponent	4
SINR threshold	3.5 dB
D	4
Simulation Area	5000m X 5000m

The simulations were performed for five clustered vehicular scenarios with different numbers of vehicles. Vehicles were clustered using the distributed multi-hop the clustering algorithm proposed in [1]. Based on the used clustering algorithm, vehicles choose their CHs in at most D-hop communication distance. Also, vehicles choose the most stable route to their CH. The transmission power for each transmitter is set to 100mw or 20 dBm. The other simulation parameters are listed in Table 1.

To evaluate our proposed LA scheme, we compare the following metrics: (1) number of activated links; (2) number of cancelled links.

A. Number of Activated Links

The number of activated links is the maximum number of communication links which can work concurrently without interfering with each other. As shown in Fig.3, the number of activated links in our proposed scheme is higher than the number of activated links for the scheme proposed in [4]. The reason for this result is using MUDs which provides the possibility of decoding and cancelling the strong interfering links. Consequently, the cancelled interfering links can be removed from denominators of signals of interest. This increases SINR of signals of interest and subsequently increases the number of activated links. To better illustrate the results, we show in Fig.4, the number of activated links for the scenario with the smallest cluster in terms of the number of vehicles.

Fig.3 also shows that when the network gets denser, LA's improved performance with PIC is much more visible compared to LA without interference cancellation. In dense networks, the interfering links number increases, which degrade the performance of LA without interference cancellations.

B. Number of Cancelled Links

Fig.5 shows the number of cancelled links among the interfering links which have been examined for the cancellation using PIC. As illustrated, the number of cancelled links increases as the network gets denser. For example, as illustrated in Fig.5, in the scenario with 31 available links (links of interest), 37 interfering links are cancelled which is more than the number of available links. The reason is because in a dense network, the interfering links are stronger and it is much easier for receivers with MUD capability to decode the interfering links and cancel them.

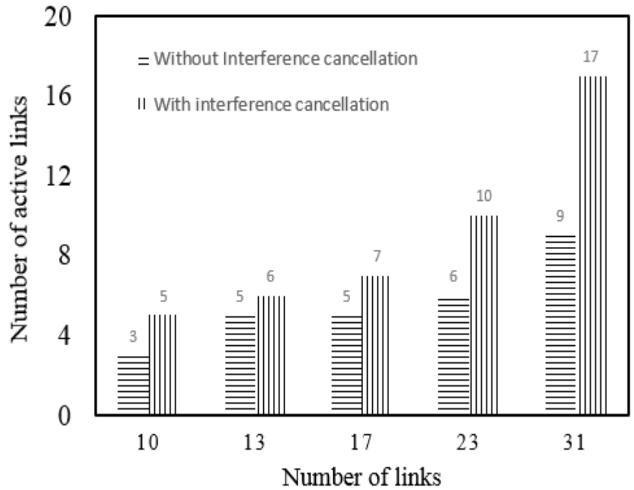

Fig. 3. Number of activated links versus the number of available links (links of interest).

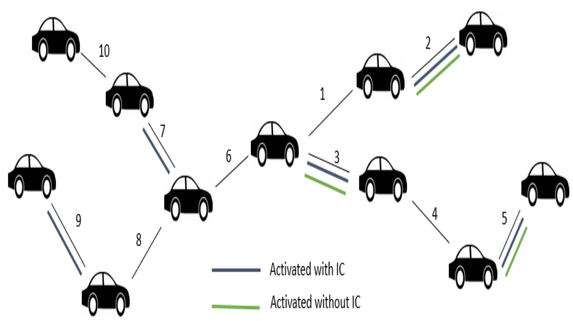

Fig. 4. Clustered vehicular scenario with repressed LA results.

VI. Conclusion and Future Work

In this paper, a novel LA scheme with PIC is proposed for multi-hop clustered VANET. In the proposed scheme, receivers are capable of cancelling the strong interfering signals. The proposed LA increases the number of active links which can be used simultaneously. We plan to use this scheme for scheduling transmissions in multi-hop VANETs, similar to [4], where a contention free transmission scheduling is presented.

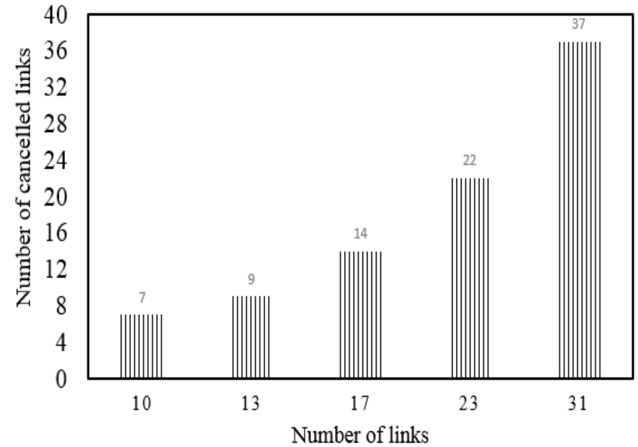

Fig.5. Number of cancelled links versus the number of available links (links of interest).

VII. Bibliography

[1] M. Azizian, S. Cherkaoui and A. Hafid, "A distributed d-hop cluster formation for VANET", in *IEEE Wireless Communications and Networking Conference (WCNC 2016)*, Doha, Qatar, 2016.

[2] M. Azizian, E. Ndih and S. Cherkaoui, "Improved multi-channel operation for safety messages dissemination in vehicular networks", in *Divanet14*, Montreal, 2014.

[3] S.Vodopivec, J. Bester and A. Kos, "A survey on clustering algorithms for vehicular ad-hoc networks", in *35th International Conference on Telecommunications and Signal Processing*, Prague, 2012.

[4] M. Azizian, S. Cherkaoui and A. Senhaji Hafid, "A distributed cluster based transmission scheduling in VANET", in *IEEE International Conference on Communications (ICC)*, Kuala Lumpur, 2016.

[5] D. Yuan, V. Angelakis, L. Chen, E. Karipidis and E. G. Larsson, "On optimal link activation with interference cancellation in wireless networking," *IEEE Transactions on Vehicular Technology,* vol. 62, no. 2, pp. 939 - 945, 2012.

[6] R. Ghaffar and R. Knopp, "Spatial interference cancellation algorithm", in *IEEE Wireless Communications and Networking Conference*, Budapest, 2009 .

[7] Z. Zhang, A. Boukereche and R. Pazzi, "A novel multi hop clustering scheme for vehicular ad-hoc networks", in *DIVANET*, Miami, 2011.

[8] M. Pioro, M. Zotkiewicz, B. Staehle and D. Staehle, "On max–min fair flow optimization in wireless mesh networks", *Ad Hoc Networks,* vol. 13, no. 1, pp. 134-152, 2014.

[9] "GUROBI," [Online]. Available: http://www.gurobi.com.