A Social-Based Approach for Message Dissemination in Vehicular Ad Hoc Networks

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Abstract. The spreading of messages in a vehicular network is an important task and finds many applications in Intelligent Transportation Systems (ITS). A common problem to this direction is to select an appropriate set of vehicles that on behalf of a sender will further rebroadcast the message and reduce redundant retransmission. Of particular interest is the use of social inspired metrics to identify potent vehicles which can set the right path for the spreading of messages and cover a wide range of a vehicular network. In this work we propose a novel approach for selecting vehicles based on the *Probabilistic Control Centrality (pCoCe)*, which accounts for the number of directed and diverse paths emanating from each individual vehicle. We evaluated our approach and compared with the standard IETF, *Optimized Link State Routing Protocol (OLSR)*. Our experimental results show that *pCoCe* outperforms its competitor in various network conditions by at least 10%.

Keywords: Multipoint relays · Broadcasting protocols · Influential spreaders · Vehicular ad hoc networks · OLSR

1 Introduction

Vehicular ad hoc networks (VANETs) provide peer to peer communication between vehicles Some of the most challenging fields in VANETs include the routing of information messages among vehicles as well as the reliability in package delivery due to their dynamically changing topology. Traffic congestion phenomena, the increased number of car accidents, the environmental impact in CO2 emissions etc. urges for the use of inter vehicle communications to increase safety, comfort and ensure a greener road environment. There are plausible circumstances were one to all communications is a great asset and may affect the entire network topology. Consider cases were a driver near a parking lot broadcasts a message concerning limited free spots. Nearby interested drivers may decide to follow to this location whereas further away vehicles are less likely to do so. Generally vehicles informed of unfavorable road conditions, for example of blocked roads, traffic jams or accidents will take prompt actions to alternate their route in order to avoid those locations and thus save time and fuel. To this direction the effective dissemination of messages (i.e., broadcasting a message to the largest possible portion of the vehicular network) plays an essential role.

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The main goal of broadcasting (one-to-all communications) is to deliver a message to the entire network or to a sufficiently large portion, while keeping the number of redundant retransmissions at minimum. This domain has rich literature. Centralized broadcasting (each node is aware of the entire network topology) [1] comes with unacceptable communication cost for maintenance, and thus cannot be utilized in dynamic networks such as VANETs. Geocasting [2] is another broadcasting approach for the delivery of messages to wireless nodes located in a specific geographic region, data dissemination and warning notifications. Other studies include the use of connecting dominating sets (CDS) as proposed in [3] to extract a 'backbone' image of a network. Nevertheless, in vehicular networks with high mobility and intermittent connections maintaining an accurate backbone image is a costly strategy. More sophisticated approaches include those studied in [4]. Here a vehicular network is divided in groups of neighbors called clusters. For each cluster a leading vehicle, the cluster head (CH), is elected and assigned with specific functionalities i.e., rebroadcasting. When a vehicle has a message to send, it communicates with his CH who is then responsible to rebroadcast the message to neighboring CH's (or *gateways*) and so on until the entire network is covered. In this study we are interested in methods which do not induce significant additional communication costs such as by using CDSs or CHs.

Flooding a message throughout the network is a frequently used technique in wireless ad hoc structures. The simple flooding algorithm however causes the broadcast storm problem [5]. Other flooding based approaches include cases where nodes decide whether or not to rebroadcast a message based on some probability p. However this may results in occasions with either too few or too many retransmissions, which renders this flooding approach unreliable. In [6] the authors collected a list for the literature of small and large scale routing protocols and broadcasting methods. Among other studies, VDEB [7] and BPAB [8] are mentioned for selecting appropriate nodes to forward a message. However these approaches are not further modified for implementation in roads which include intersections.

OLSR [9] and also our competitor in this work, is a proactive or table-driven routing protocol i.e maintains a list of destinations and routes by periodically exchanging topology messages and is widely used in mobile and vehicular ad hoc networks. This protocol relies on employing selected nodes to retransmit a message among the nodes of the network instead of pure flooding. The selected nodes are called multipoint relays (MPRs).

In this article we exploit social inspired techniques for selecting appropriate sets of relay vehicles. We introduce the *Probabilistic Control Centrality (pCoCe)* as a one-to-all communication protocol with performance metric the total number of vehicles informed at the end of a notification message event. As a competing method we utilize the MPR set selection mechanism of the IETF standard *OLSR*. Our experimental results show that there are many occasions, where the minimum selected set of relays as identified by our competitor is not necessarily propitious to reach a sufficiently large part of a network. The rest of this article is organized as follows. Section 2 binds the work of influential spreaders with the relay selection process, further explains our proposition and broadly reviews the competitors. Experimental design and results are thoroughly illustrated in section 3 and finally in section 4 the conclusions.

2 Influential Nodes in Complex Networks

The analysis of complex networks has recently gathered the interest of the research society. A very important aspect lies in the identification of influential entities, i.e., detect those node-entities in a complex structure where by exploiting their connection patterns, or their topological position in a graph, a sufficiently large portion of the network can be influenced. These 'super spreaders' will be used to either boost spreading in case of fast dissemination of messages. Vehicular networks are also complex networks since their constantly changing topology creates network structures with non-trivial topological features. Our objective in this study is to use vehicles that according to some criterion play an important role in a network and exploit them to maximize the spreading of messages. In [10] the authors argued that nodes positioned in the "core" of the network as identified by the k-shell decomposition algorithm are capable of achieving the most efficient spreading; different and more local approaches are proposed in [11].

As mentioned earlier for vehicle networks the fast dissemination of a message that covers the largest possible portion of a network is a very important issue and finds fertile ground in many applications, from safety and precaution mechanisms to comfort and fuel saving applications. In this article we leverage metrics from complex network theory used for the identification of influential nodes and particularly we propose a novel method the *pCoCe* based on *Control Centrality* [12] that efficiently detects potent vehicles for disseminating messages.

2.1 Control Centrality

In [12] the authors introduce the concept of *Control Centrality* with view to identify nodes with the ability to 'control' (drive to a specific state) a directed network based on an initial input and a 'control goal'. To further investigate on the issue let us first note some definitions. A *stem* on a directed graph, is a directed path consisting of n nodes and $n-1$ edges where no node appears more than once e.g. $i \rightarrow j \rightarrow k \rightarrow l \rightarrow m$. A *cycle* is noted as a *stem* ending on the initial node: $i \rightarrow j \rightarrow k \rightarrow i$. A *stem-cycle disjoint subgraph*, is a subgraph of the directed network where stems and cycles have no nodes in common. For any node i its control centrality is defined as the largest number of edges among all possible stem-cycle disjoint subgraphs.

The purpose of this article is to exploit vehicle-nodes with high *pCoCe* values for use as multipoint relays. The intuition lies on the idea that those selected relays will rebroadcast a message on behalf of the initial sender and will likely cover a sufficiently large part of the vehicular network.

2.2 From Control Centrality to pCoCe

As a first step we must define incoming and outgoing neighbors in vehicular networks. Since all connection links among vehicles are considered bidirectional, we use the relative direction between them to classify them either as in or outgoing neighbors. Generally vehicle A is considered an outgoing of vehicle B when A is moving either in front of B or away from B in a different direction. For instance in Figure 1 and for vehicle 7 the set of it's outgoing neighbors includes vehicles 1,3 and 6 while the rest synthesize it's ingoing vicinity.

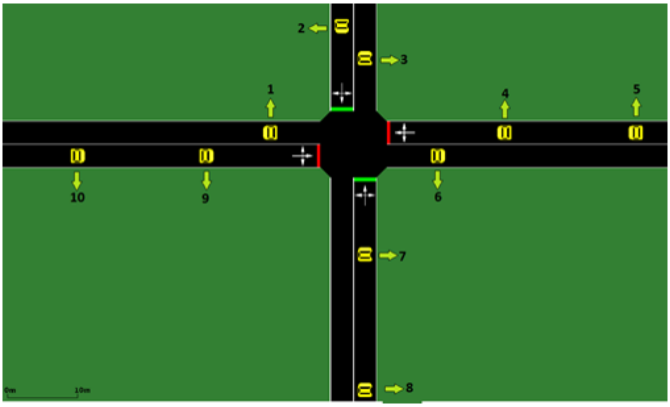

Fig. 1. In and out neighborhoods of a typical vehicular network

With this consideration we can define stems and cycles in VANETS. However the use of cycles to enhance a vehicle's importance in a vehicular network is very likely to overestimate the vehicles ability in disseminating a message to a large part of the network. Hence from here on we account only for stems, created from vehicle paths.

The original control centrality algorithm is computed with stems and cycles which cover the entire range of a network. However in VANET's due to their constantly changing topology and connection pattern (neighbor vehicles increase or decrease their distance in and out of the communication range or in-neighbors become out and vise versa) we cannot utilize the method in full range. In this study we confined our selves to a range of two and three hops distance (*2pCoCe, 3pCoCe*).

Note that *pCoCe* uses all stems within our specified range and there are occasions were different stems have common edges. These stems will all contribute in the final *pCoCe* value for a vehicle-node and form it's final index. At this point we would like to note that our new method is a novel approach that considers and combines different stems emanating from a particular vehicle and define its significance in the network.

The last part of *pCoCe* accounts for the strength of connections between vehicles (*stem power*) and incorporates this attribute in the formed stems. Depending on the quality of the connection for each out-neighbor we assign a weight value between 0 to 1 depicting the strength of connection between the two vehicles. Weights close to 1 depict a perfect communication link whereas values close to 0 depict an almost absent connection. The *stem power* is computed as follows:

$$Sp = S \cdot PW \tag{1}$$

where S depicts the size of a stem in edges and PW is the product of the weights that form it. In this work we consider all weight values to be equal to 1. Further investigation for the strength of connections and its incorporation in Sp is a very interesting task, but it's beyond the scope of this study.

Finally in order for a vehicle to accumulate its final $pCoCe$ index it sums all the different Sp's to a final value which will characterize its importance within its vicinity:

$$pCoCe(x) = \sum_i Sp(i) \tag{2}$$

where i denotes the different stems emanating from vehicle x.

2.3 pCoCe Relay Set Selection

$pCoCe$'s algorithm for selecting relays is straightforward. Every vehicle sorts its out one hop neighbors in descending order of their $pCoCe$ values. The neighbor with the maximum value is selected as a relay. In the sequence the next highest neighbor is examined. If additional out two hop neighbors are reached, this vehicle is included in the relay set and so on until the entire two hop neighborhood is covered. At this point we should note that only the out one and two hop neighbors are considered for the selection process. The pseudocode is given in Algorithm 1. One final modification of the $pCoCe$ is needed in order for a sender to select an appropriate relay set. Some of the accumulated Sp's that are used in order to form the $pCoCe$ value may be incoming stems to the sender i.e., the final vehicle on a stem may be an incoming neighbor. Those vehicle stems should be excluded from the computation of the final index. To this end when a vehicle needs to broadcast or rebroadcast a message it dynamically asks from its out one hops to compute and respond with their $pCoCe$ values excluding stems incoming to the sender. Finally the returned values are multiplied by the number of the two hops covered by each respective out-neighbor. Note that at this point we introduce an additional communication phase and thus an additional delay before sending the message.

2.4 OLSR MPR Set Selection

The notion of in and out going neighbors is also induced into the MPR selection process of OLSR in order to select relays from identical vicinities in both approaches and thus only out one and two hop neighbors are considered. OLSR

```
Result: Select appropriate relay set
x : a vehicle
N(x) : set of one hop out neighbors
N^2(x) : set of two hop out neighbors
MPR(x) : multipoint relays for x
Vector_x : neighbor pCoCe values in descending order
if Notification Event then
    MPR(x) = ∅
    Vector_x = ∅
    Request one hop out neighbor pCoCe values.
    MPR(x) ← Vector_x[0]
    Delete Vector_x[0]
    while ∃ vehicle in N^2(x) not covered by MPR(x) do
        MPR(x) ← Vector_x[0]
        Delete Vector_x[0]
    end
end
```

Algorithm 1. Pseudo-code for pCoCe relay set selection

first selects vehicles who provide unique access to some two hop neighbors. In the sequent the vehicle that covers the maximum remaining two hop vicinity is selected and so on until the entire two hop neighborhood is reached. The pseudocode for the MPR selection process is given in Algorithm 2.

```
Result: Select appropriate mpr set
x : a vehicle
N(x) : set of one hop out neighbors
N^2(x) : set of two hop out neighbors
MPR(x) : multipoint relays for x
Compute Mpr Set:
MPR(x) = ∅
Select those one hops from N(x) that are the only neighbor of some vehicle in
N^2(x).
while ∃ vehicle in N^2(x) not covered by MPR(x) do
    ∀y ∃ N(x) & y ∄MPR(x): compute the number of vehicles that each y
    covers among the uncovered vehicles of N^2(x).
    Add to MPR(x) the vehicle with the maximum number.
end
```

Algorithm 2. Pseudo-code OLSR MPR set selection

3 Performance Evaluation

For the evaluation purposes and for our experimentation we use the open source vehicular network simulation framework, VEINS [13], which uses SUMO for the traffic simulation and OMNET++ the network simulation framework.

3.1 Simulation Design

Grid Network. We evaluated the performance of *pCoCe* in a grid road network topology (3X3). The network includes road segments with two direction flows and every $2km$ there are intersections with traffic lights providing a coordinated traffic flow. The competitors where evaluated under different circumstances concerning the range of communication, the velocity of vehicles and the density of cars on the road network. Particularly we experimented with vehicle velocities of 14, 20 and $28m/s$ and range of communication at 250 and $500m$. For the density of the scenarios we introduce a vehicle every 1, 5, 10 and 15 seconds, ranging from very dense to very sparse network topologies. The average number of vehicles to the corresponding frequencies is 950, 250, 170 and 120 cars respectively. Vehicle flows enter the simulation from different road segments of the grid network.
Communication Between Vehicles. All vehicles are communicating through DSRC with range of communication as previously noted in 250 and $500m$. For every vehicle in order to be aware of its vicinity, beacon messages are exchanged every 1 seconds. In order to maintain an updated image of its surroundings, every vehicle that has not received a beacon message from recoded neighbors for more than two seconds i.e., missed two consecutive beacons, updates its vicinity by removing those vehicles. This ensures that each vehicle has a clear and very recent image of its neighboring cars.
Notification Message Event. The dissemination of notification messages is triggered upon notification events. A notification event is generated from a random vehicle at a random position on the road network (the same vehicle for both approaches) with only one notification existing at a time. The results are averaged over 10 different events for each competing method.

3.2 Dissemination to the Entire Grid

Experimenting on Vehicle Density, 2pCoCe. The aim of this first experimentation set is to conclude whether the conservative MPR set selection of OLSR is adequate for informing a sufficiently large part of a vehicular network. The results are illustrated in Figures 2 to 4. On the x-axis we depict the frequency to which vehicles are introduced in the simulation in seconds, while keeping the velocity constant at 14, 20 and $28m/s$ respectively. Communication range is set to $500m$. The results are given in percent depending on the number of vehicles present in the simulation at the time of the notification event.

In all but one cases OLSR fails to exceed the percentage of the vehicular network covered by *2pCoCe*. The results in Figure 2, set with the lowest speed ($14m/s$) in our experimentation, show that the frequency of vehicles does not have a significant impact on our approach. Our method manages to find the right paths for the spreading of messages and inform the vehicular network at near 80%. For our competitor the worst case performance is illustrated for the dense scenarios. This indicates that OLSR when faced with many options for selecting MPR vehicles cannot distinguish an appropriate MPR set for the most efficient spreading of messages. Considering the sparser scenarios in the same Figure, and thus with fewer choices, OLSR's performance is improved. Nevertheless the competitors show a difference in percent coverage of more than 25% for the best case of OLSR.

In Figures 3 and 4 we repeat our experimentation with increased speeds to 20 and 28m/s respectively. Increasing the velocity of vehicles will result in a more frequently changing topology among a vehicle's surroundings and thus a more profound selection is crucial. As illustrated *2pCoCe* is performing extensively well when dealing with a large number of potential choices for the relay set. The coverage rate rises up to more than 90%. OLSR significantly fails to keep up with our approach. In the last illustrated example for this set of experimentation, Figure 4, *2pCoCe* shows a decreasing performance as we move to sparser network topologies. This indicates a more reliable and trustworthy behavior in contrast to OLSR showing extensive fluctuations in coverage when changing the network density at a relative high speed.

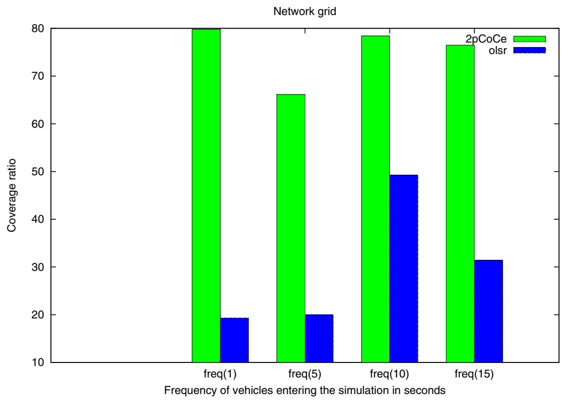

Fig. 2. OLSR Vs 2pCoCe with vehicle velocity at 14m/s

Differences in the Selected Relays. In Figure 5 we normalize the size of the network that received the message with the number of MPRs selected by each competing method, through the entire spreading process. Since OLSR makes a conservative choice for his MPRs a frequent phenomenon is that the spreading dies after a few hops (due to false relay set selection) and thus covers a significantly lower portion of the network. Since the spreading for *2pCoCe* continues in further broadcasting circles than our competitor, more vehicles are selected in subsequent steps as relays.

As far as the average number of MPRs per vehicle is concerned OLSR selects the minimum set of relays. However as shown through our experimentation in many cases OLSR results into very poor spreading compared to our approach. For the dense scenarios with vehicles entering the simulation every 1 or 5 seconds, *2pCoCe*'s relay set is greater than OLSR's by one or two vehicles whereas for the

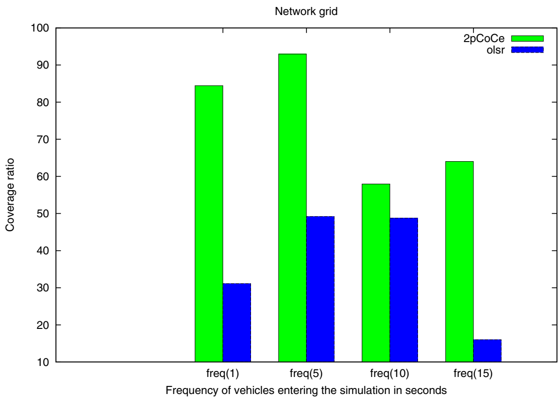

Fig. 3. OLSR Vs 2pCoCe with vehicle velocity at 20m/s

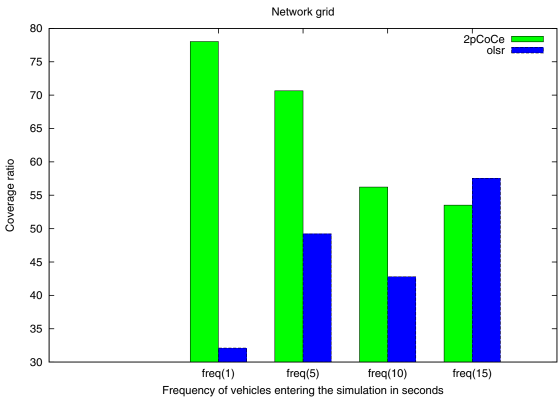

Fig. 4. OLSR Vs 2pCoCe with vehicle velocity at 28m/s

cases of 10 and 15 seconds we have either equal sets or our set is greater by one. By equal or greater sets we are merely referring to the number of relays selected by each method. Indeed there are occasions were the competitors select similar sets of vehicles, however on average different relays are chosen as identified by each algorithm. Reviewing the differences in coverage rates for both methods in Figures 2 to 4 one or two additional relays is a good trade-off when a significantly larger part of the network is reached.

Increasing the Range of pCoCe to 3 Hops Distance. In this set of experiments we evaluate the performance of *pCoCe* when increasing the distance of interest from 2 to 3 hops. The results are illustrated in Figure 6. When vehicles enter the simulation every 1 seconds, regardless of their velocity, *3pCoCe* covers a greater percent of the vehicular network than *2pCoCe* and thus greater than OLSR. This indicates that *3pCoCe* (and also *2pCoCe*) performs extensively well

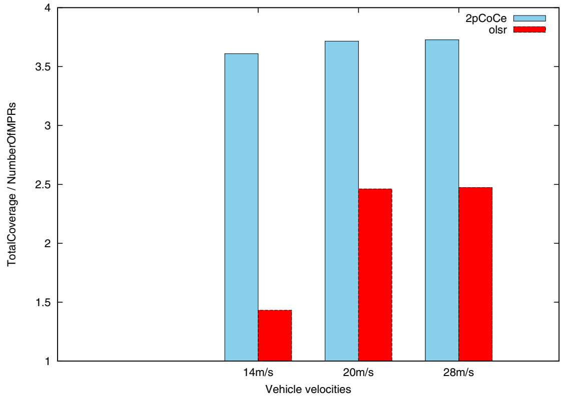

Fig. 5. Normalize coverage by number of selected mprs of each method

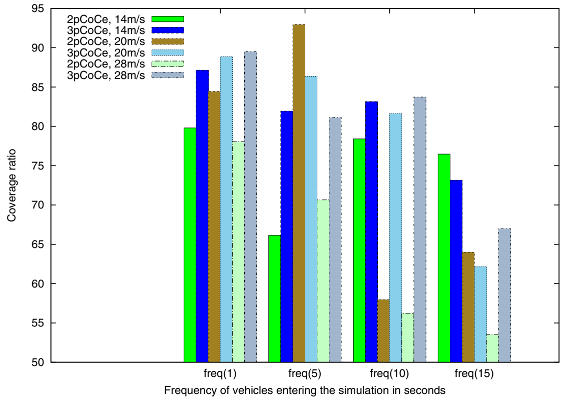

Fig. 6. Comparing pCoCe's performance with 2 and 3 hops distance

in very dense scenarios by selecting potent vehicles for rebroadcasting with total percent of coverage over 85%. For vehicle frequencies of every 5 and 10 seconds as shown in our experimentation, *3pCoCe*'s coverage is constantly higher than 80%. Our algorithms performance seems to start getting affected by the vehicle velocities when examining the sparse scenario where vehicles enter the simulation every 15 seconds. Nevertheless the coverage percentage reached by *3pCoCe* is about 63% for the worst case of its performance and up to approximately 73% at best. For OLSR the best coverage rate in this scenario rises up to about 56%.

Reducing the Range of Communications to 250m. Considering only out one hop vehicles as potential relays can be considered a 'hazardous' approach. As noted in section 2.2 out going neighbors are those who either move away from a sender to a different direction or positioned ahead of a sender and moving towards the same direction. Thus these are the vehicles which are most likely to 'exit' the communication range of a sender, sooner than other neighbors. In Figure 7 we illustrate the obtained results with vehicle frequency set at 1 seconds and communication range at $250m$. Excluding results at $28m/s$, $pCoCe$ provides a wider range of the network coverage than OLSR for 2 and 3 hops distance stems. Analogous results were obtained for 5 seconds frequency, however both the algorithms performance drop below 10% when considering the sparser scenarios. Let us elaborate a little more on the impact of the communication range on $pCoCe$. As mentioned earlier our approach calculates stems of vehicles of 2 or 3 hops distance from a sender car. These stems are composed of outgoing neighbors (excluding paths incoming to the sender) and thus further expand the hazardness of outgoing vehicles to additional hops. Therefore $pCoCe$ when limited to a very short communication range performs best in minimum stem distance, i.e., 2 hops.

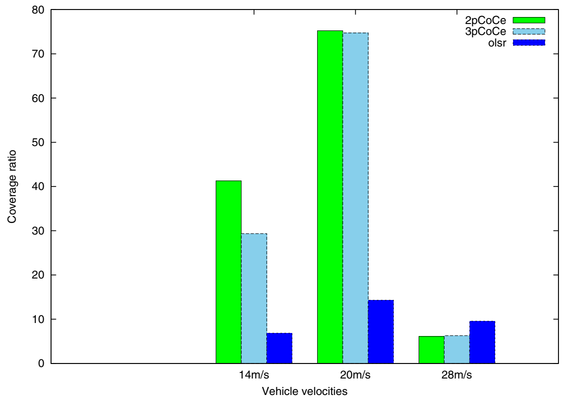

Fig. 7. Communication range at 250m for frequency of vehicles every 1 seconds

4 Conclusion

In this paper we presented a novel approach for the selection of relay vehicles based on metrics from complex network theory and the identification of influentials. We proposed a novel broadcasting protocol which induces minimum additional communication cost and performs extensively well when dealing with a large number of potential relay choices. Our competitor fails to provide both an adequate coverage rate and reliability as illustrated under diverse simulation parameters. As future work incorporating the quality of links in the *'stem power'* will provide valuable insights in broadcasting a message under harsh communication environments and different road topologies.

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