LIKE VEHICLES LIKE PEDESTRIANS, IN AN INTERCONNECTED WORLD

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ABSTRACT

We present some scenarios where a group of people walking around and linked together by a common intent could take advantage by communicating each other by means of their smartphones and tablets implementing an ad–hoc network.

We show the results of a study for extending to walking pedestrian of an optimal broadcast for platoon of vehicles traveling on a road. The extension has the scope of porting the original broadcast from a mono–dimensional space to a bi–dimensional one. The pedestrians could walk in open spaces and are not constrained to move along roads or walkway.

We could consider that each person brings its own smartphone or tablet. The current models of these devices offer enough computational power to run both a communication mechanism and an overlying application. We started from an optimal and lightweight P2P communication system for vehicles. Smartphones and a tablets are devices fully equipped to implement such a broadcast service by means of GPS receiver and WiFi capabilities.

We show several examples and scenarios to proof the impossibility of extend the optimal broadcast from one to two dimensions. The mono–dimensional case takes strong advantages form the underlying geometry and its key concepts became unusable in a bi–dimensional case.

***Index Terms*—** ad-hoc networks, mobility, full 2D scenario, interactivity, smartphones

1. INTRODUCTION

Nowadays we are witnessing a growing diffusion of *smartphones* worldwide. A large portion of currently used cellular phones is capable to run specialized applications, to connect to WiFi network and to receive GPS signals. Smartphones could be connected to the Internet either by means of *Wifi* or *cellular data* networks. Both of these means of communication could be not available, or properly viable, while those devices could always implement *ad–hoc networks*.

We consider a group of people walking around, each person equipped with its own smartphone running a specific application to communicate each other in a P2P fashion by means of ad–hoc network.

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We can sketch three scenarios, that differ each other with respect to GPS and WiFi availability and pattern of mobility. We consider as cellular data any kind of data transmission over the cellular phone signal, without differentiating between the generations of mobile data standards. This simplification does not affect the scenarios. Note that in the classification below we could ignore WiFi networks while our proposal does not require such an infrastructure and it is somewhat alternative to it.

Open air in this case, we can suppose that the pedestrians could walk in a large space either without constraints, such as in the countryside, or with some limitation, such as in an archeological site. We could characterize this scenario with fickle cellular data signals and robust GPS reception. WiFi networks are almost absent or sporadically available.

Urban or inside buildings pedestrians could walk either on the streets and squares or inside a building, such as museums or public edifices. In this scenario, we could suppose that GPS reception is inconstant, and could be negligible, while cellular data are reliable. WiFi networks are generally private and overlapping, each one distinct from its neighborhood.

Transportation facilities a group of persons is sitting in a train or in a bus; they are almost immobile each other but they are moving as a whole with respect to the surrounding environment. GPS reception is inconstant and cellular signals could be varying. Onboard WiFi networks are rarely available, while external ones are almost unaccessible.

It is worth mentioning that some train companies are starting to offer WiFi connections on selected trains, usually their top class ones, and that some airline companies are announcing the imminent introduction of some WiFi capabilities is selected fights and aircrafts. As an example, consider that in Italy some high speed trains, that largely travels at 300Km/h, offers a reasonably fast onboard WiFi connection to its customers, while moving at that speed makes the cellular signal barely usable.

In all the above scenarios the cellular data connection to the Internet could be inadequate to establish a communication channel inside a group of people because it could be either too slow and discontinuous, or excessively complex to put to good use.

While walking, pedestrians can use the cellular data connectivity to access the Internet while they receive the cellular signal by a proper provider. While on board of a public transportation mean the cellular signal could be scattered because either the specific coverage of the providers or because the speed of traveling.

there are several scenarios where ad-hoc networks between smartphones could be put in good use to establish communications inside a group of people. As examples we could consider: *i)* interactive multiuser gaming between people onboard of the same mean of transportation or public commuters; *ii)* interactive VoIP and multimedia exchange in guided tours of cities and sites; *iii)* site specific information related to public buildings (*i.e.* how long is certain waiting queue, the ordering number of the serving customer).

The basic idea is that ad-hoc networks could be an easy means to connect people relate each other by physical location and common intents. Instead of using the Internet to search for each other and to identify themselves as temporarily member of a specific group, the persons could run a specific application to this scope. The application could connect the member of the group allowing them to reliably communicate and exchange data each other.

We decided to study the possibility of utilize a broadcast protocol for vehicular networks to our purposes. We focussed on the optimal broadcast protocol for VANET described in [1, 2] implemented for safety applications and applied to prevent real time traffic congestion [3]. This protocol is optimal with respect to the number of hops, *i.e.* the time of propagation, required to broadcast a message to a platoon of vehicle traveling on a road.

In this paper we show the lessons learned when extending such an optimal protocol from a mono–dimensional scenario to a bi-dimensional one.

The remaining of that paper is structured as follows. The section §2 sketches the main characteristics of the optimal method for traveling vehicles, that is in a single dimension. Section §3 analyzes how the above described characteristics change when ported to the case of pedestrian walking around, *i.e.* into a bi–dimensional scenario. The section §4 describes some implementation topics related to a possible smartphone application. At last, section §5 concludes the paper summarizing the main results.

2. TRAVELING VEHICLES

The work presented in [1, 2] achieve optimal communication by means of ad-hoc network, over the standard IEEE 802.11p, between vehicles that are traveling on a road without any network infrastructure. The proposed method is optimal kind of *flooding* that takes advantage of strictly local knowledge, and takes into consideration both the realistic assumptions that each vehicle could have its own range of transmission that could vary while traveling [4].

To detect its position, each vehicle uses a GPS receiver, while it gathers the values of other attributes by exchanging data with its neighborhood. Essentially, each vehicle regularly transmits its position and the set of its known neighborhood by means of *oracle messages*. Based on this regular exchange of oracle messages, each vehicle could asses its actual transmission range and the set of surrounding vehicles, and their own transmission ranges.

When a vehicle broadcasts an *application message*, such as safety messages, it appends to the message the list of best relays for that message. The list of best relays is ordered on the maximum reach that each one of these relays can gain, that is the individual sum of their distance from the source and their transmission range. It has been mathematically proven that this approach gains the minimum number of hops to broadcast an application message to a platoon of vehicles traveling on a road. Moreover, following this approach, the broadcasting system is able to tolerate $n-1$ relays faults for each application message, when n is the cardinality of the list.

2.1. Asymmetric communications

The vehicles could have individual and varying transmission ranges that lead to *asymmetric communications*. We define such a transmission path when vehicle R receives the transmission from vehicle S, but not *vice versa*. Figure 1 shows an example of asymmetric communications. Vehicle S has a transmission range that spans ρ_S and reaches vehicle R, therefore the messages from S are straightly received by R. This is represented by the arch of circle centered in S with radius ρ_S that contains the node B. All the transmission ranges in that figure are represented by analogous graphical symbols. Vehicle R has a shorter transmission range, ρ_R hence its direct communications does not reach S. To allow messages from R to reach S it is necessary that at least one intermediate vehicle could relay those messages, therefore implementing a multi-hop communication path from R to S. In the example shown in the figure there is only one intermediate vehicle, labelled 1.

Each vehicle could assess its transmission range and the set of surrounding vehicles by means of the exchanged oracle messages mentioned above. In the example shown in Figure 1 the vehicle S could assess its transmission range ρ_S

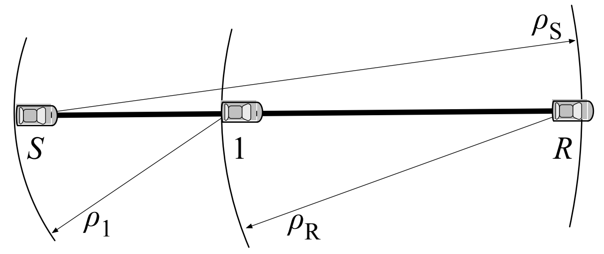

Fig. 1. Asymmetric communication between vehicles S and R traveling on a portion of road.

because of the relative position of vehicle R that received the transmission and that broadcasts this information into its oracle messages. Moreover, thanks to the regularly exchanged oracle messages the S knows: what are the vehicles that it reaches, *i.e.* its neighborhood, their relative position and their measured transmission ranges.

2.2. List of relays

By means of the list of relays that each sender appends to any application message, the multicast has several properties: *i)* reduces the *messages shower* typical of a classical flooding broadcast, *ii)* tolerates several relays failures and *iii)* gains the minimum number of hops.

When a vehicle receives an application messages it looks for its position into the list of relays attached to that message. If the vehicle is not in that list it will never relay that message. Otherwise, the vehicle waits a period proportional to its position in the list before to relay the message, *i.e.* the first vehicle on the list does not wait all, whereas the followings wait an increasing amount of time. While waiting to relay a message, a vehicle could detect a relay of that message from a vehicle preceding it in the list of relays; in that case the vehicle drops that relay process because another one took care of it.

This technique greatly reduces the number of relays of each single message with respect to a classical flooding mechanism. In the latter case each receiver has to relay the message when receiving it for the first time, causing the so called *messages shower*. Therefore, the above technique reduces both the congestion of the communication channel and the probability of collisions between retransmissions of the same message.

A further advantage deriving from the above technique is a kind of *fault tolerance*. If the vehicle in charge of the relay misses, for any reason, its retransmission, there are solid chances that this relay will be performed soon by one of its successors in the list of relays. The only disadvantage will be a slight lag in the time to broadcast that message.

The vehicles in the list of relays associated with an application message are ordered on the reach that they will gain. The first vehicle of the relays list is the one whose transmission spans farther with respect to the source, and that allows for the minimum number of hops.

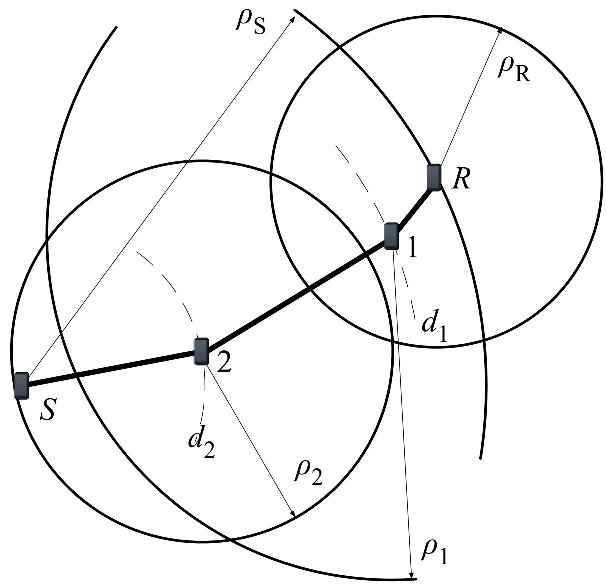

Fig. 2. Communication path from node R to node S in the case of intermediate nodes located at decreasing distances form node S.

3. WALKING PEDESTRIANS

The methodology sketched above have been developed for a one dimensional scenario such as vehicles traveling on a road or a freeway. We discuss in the following how to extended to bi-dimensional spaces these results, as far as possible.

To underline the difference between mono and bi dimensional scenarios we use the term *nodes* instead of *vehicles*.The latter is very specific while the former is a more generic term to underline both the node, usually a walking person, and the scenario inside which it moves.

In the following we discuss asymmetric communications and optimization of relays that are key topics in the mono-dimensional cases.

3.1. Asymmetric communications

The asymmetry of communications, that were a central topic of previous works on mono–dimensional roads, become a complex problem to face on bi–dimensional planes. The key concept to manage asymmetric communications between vehicles traveling on a road is that intermediate vehicles relay the messages. In a bi–dimensional space, the concept of intermediate node it is harder to define and, more generally, it is quite complex even to designate which nodes should relay a message.

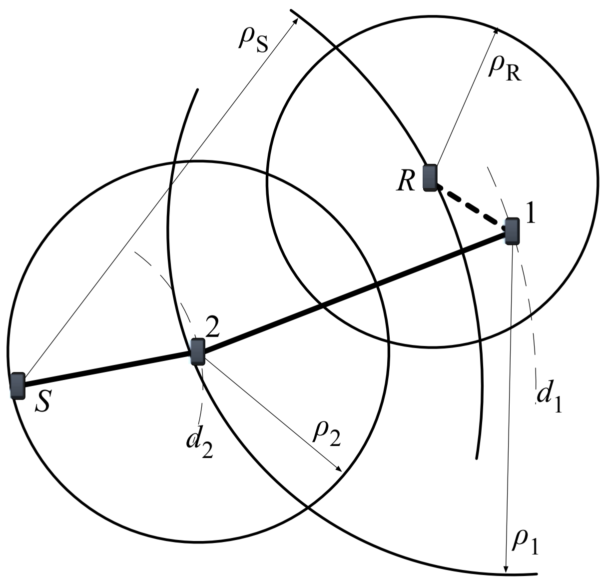

Fig. 3. Communication path from node R to node S in the case of intermediate nodes located at non decreasing distances form node S.

At a glance, it seems that asymmetric communications in a bi–dimensional space could be easily managed by intermediate nodes, as shown in Figure 2. Suppose that the sending node, labelled S, sends an oracle message that spans ρ_S and it is received by the farthest node R. The arch of circle centered in S with radius ρ_S that passes trough the node B represents this transmission. Then, node R transmits its own oracle message, that spans ρ_R, that contains, among others, the statement "R received from S". The circle centered in R with radius ρ_R represents this transmission. Note that since $\rho_S > \rho_R$ the node S does not receive that message and therefore cannot asses its ρ_S.

Since node 1 received the oracle message from R and knows, by their relative positions, that it is in the between of nodes S and R it includes in its oracle messages the information that "R received from S". Even in this case, node S does not receive the relay of that information from R because the distance d_1 between S and 1, is bigger than ρ_1. Following the same considerations of node 1, event node 2 will relay the information from R.

Finally node S will receive the information from R, while $d_2 < \rho_2$, and then could assess its range of transmission ρ_S. The solid segments from R to S represent the communication path defined by the messages from R to S. Each single hop in that path nears the message to its destination. In the opposite direction, the transmissions from S are straightly received by R.

Unfortunately, it could be the case that asymmetric communications have to be managed by nodes that are not located

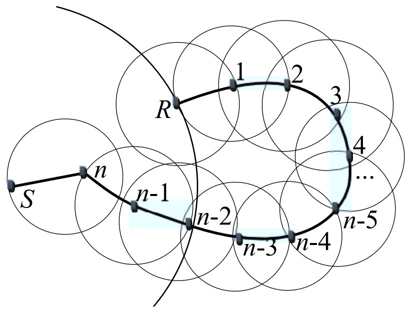

Fig. 4. Communication path from node R to node S in the case of intermediate nodes that are also located far from S.

between the sender and the receiver of a transmission. There are cases where asymmetric communication could be managed solely by nodes farther than the receiver with respect to the sender, as shown in Figure 3. The figure depict a scenario almost identical to the one shown in Figure 2 except that node 1 is farther than node R with respect to node S, that is $d_1 > \rho_S$. This scenario could be described exactly as the previous case, but the first hop in the communication path from R to S moves away the message from S instead of nearing it. That first hop is represented by a dotted line from R to node 1. Note that this is the only possible communication path from R to S.

The above scenario could be worsen by considering that the communication path from R to S could move the messages from R to S considerably far away from their destination, an example of that case is shown in Figure 4. The relative positions and transmission ranges of nodes S and R are the same as shown in the previous figures, and nodes from 1 to n constitute a chain of communication from R to S made of n hops. The higher the value of n the the longer a message takes to reach its destination. In other words, a long communication path is ineffective because conveys outdated informations.

Due to the above examples, it seems that a possible designation of intermediary nodes, *i.e.* the ones that will relay oracle messages, could be based on the distance form the sending node. A comparison between Figures 2 and3 seem to suggest that solely the nodes whose distance is decreasing could be effective relays. The example show in Figure 4 strongly reinforces this idea to avoid useless long communication paths. A possible path of communication from R to S should be made by nodes $\{1, 2, \ldots, n-1, n\}$ where the distance from S are $d_R \geq d_1 \geq d_2 \geq \cdots \geq d_{n-1} \geq d_n$.

Sadly, even this simple approach could lead to wrong results, as shown in Figure 5. In that case the only possible path of communication from R to S is the one made by nodes $\{1, 2, 3\}$. It is easy to verify that while $d_R \geq d_1$ it is not true that $d_1 \geq d_2$, *i.e.* the node 2 if father than node 1 with respect to node S.

The above examples show that a simple and effective

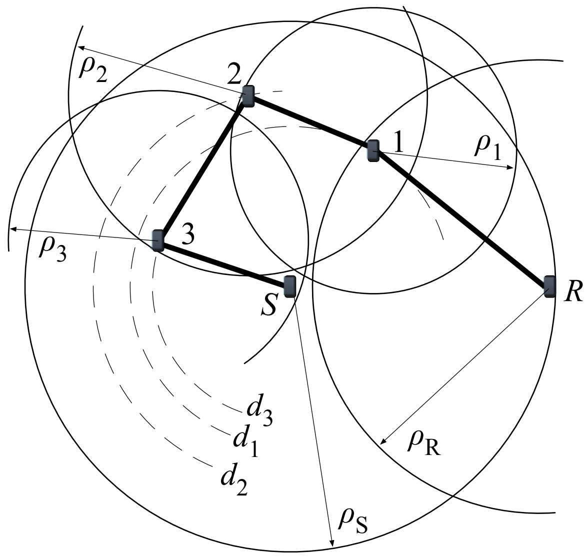

Fig. 5. Communication path from node R to node S in the case of intermediate nodes located both closer to S with respect to R and at non decreasing distances form node S.

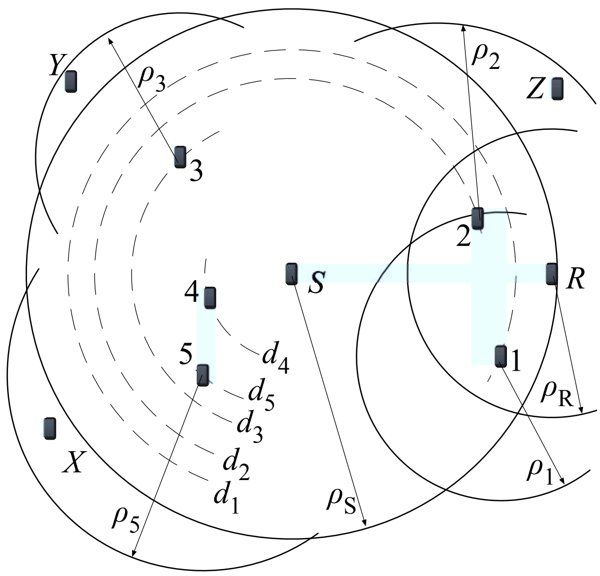

Fig. 6. Several relays to complete a broadcast form node S

idea to manage asymmetric communication in a mono–dimensional scenario is inefficacious when extended to a bi–dimensional scenario. Even the idea of "intermediate node" needs a much more complex definition. Trying to manage asymmetric communication in a bi–dimensional space requires more than simple local knowledge, *e.g.* it requires the computation of a shortest path in a graph, that is too complex to achieve and that should be updated continuously due to the mobility of the nodes.

Due to the above considerations, we decided to drop any mechanism to take care of asymmetric communications to keep the broadcast protocol as simple and lightweight as possible. This simple approach induces a simplistic and pessimistic interpretation of the reality. It considers shorter than they are all the transmission ranges that could be detected solely by asymmetric communications.

3.2. List of relays

When extended to a bi–dimensional scenario, the list of relays should *i)* optimize the number of hops, *ii)* avoid the messages shower and *iii)* preserve some tolerance to faults.

A slight optimization could be made by excluding from the list of relays the nodes whose transmissions reach an area completely included in the one reached by the sender node.

The Figure 6 shows a scenario where the technique based on the list of relays as described in the mono–dimensional scenario fails to perform a broadcast. Without loss in generality, we can suppose that the length of the list of relays was set to 3 nodes. In the example shown in the figure, it happens that $(d_R + \rho_R) > (d_1 + \rho_1) > (d_2 + \rho_2) > \ldots$, therefore the list of relays is made of nodes $\{R, 1, 2\}$. Applying the above described techniques, node R relays the message, while nodes 1 and 2 remain silent because they sense the re–transmission from R. The remaining nodes X, Y and Z does not receive any broadcast of the message while the nodes that could have reached them remain silent because either they are not in the list of relays, such as nodes 3 and 5, or because they are not responsible for the current relay, such as nodes 1 and 2.

The optimality property that was guaranteed by this approach in the mono–dimensional case does not make any sense in a bi–dimensional scenario. When broadcasting over a surface there are two factors to consider: the distance from the original node and the completeness of the coverage of the broadcast. Those two parameters are independent each other. The approach followed in the mono–dimensional case optimizes the distance factor, while the completeness of the broadcast is not an issue because it is a direct consequence of that.

A novel approach to the list of relays in the bi–dimensional scenario should use the positions of the possible relays both for efficiency and completeness. Taking advantage of their relative positions, several relays could re–transmit the message in parallel avoiding interferences between each other. Moreover, the position of the relays could allow for the propagation of the broadcast in any direction.

4. IMPLEMENTATION PLANS

Smartphones and a tablets are devices fully equipped to implement a broadcast service as discussed above. The standard equipment of a current smartphone or tablet includes: GPS receiver, WiFi capabilities, large screen with graphical interface and enough computational power and memories to run both the communication mechanism and an overlying application.

We believe that a full access to Internet, considering even the inevitable latencies, could be inappropriate in several circumstances, as the ones shown in §1. We are investigating the best solution, possibly not depending on the operating system, to implement ad hoc networks by means of personal smartphones and a tablets. The idea is that the users should be able to download an application "al inclusive" that could allow then to communicate each other without recur to any server in the Internet.

The standard configuration of smartphones and tablets do not requires any extra hardware to be installed to implement the ad–hoc network we are thinking about. Moreover, there are several software solutions that could be used as low level layer of communication that do not require a base station to connect each other the devices [5, 6, 7].

We could consider those devices as *off–the–shelfs* basis to build up our system. However, an important issue will be the compatibility across platform, to allow to as much user as possible to take advantage of local broadcasts.

5. CONCLUSIONS

It could be advisable to implement ad–hoc networks between groups of moving persons inked together by some common intent.

We studied the possibility of extend from mono–dimensional to bi–dimensional the optimal broadcast for platoons of traveling vehicles. Unfortunately this extension is not straightforward.

We shown why an optimal broadcast for a bi–dimensional space has to be re–written from scratch with respect to a mono–dimensional case because the latter assumes too much from the underlying geometry.

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