INGEO: INdoor GEOgraphic Routing Protocol for MANETs

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ABSTRACT

In this paper, we introduce a new location-based routing protocol INGEO (INdoor GEOgraphic Routing Protocol) for ad hoc networks based on an indoor location system. We aim at extracting an optimum topology from the dynamic and irregular topology of a mobile ad hoc network to reach more quickly the destination applying an indoor geographic routing. Our scheme operates in a loop-free manner and attempts to minimize routing and storage overhead. We use Network Simulator (NS2) tool to analyze the performances of our protocol. We compare its results to DSR (Dynamic Source Routing), DREAM (Distance Routing Effect Algorithm for Mobility) and LAR (Location-Aided Routing) protocols. Also, we investigate INGEO's performance taking into account indoor characteristics. Simulation results revealed that INGEO becomes more efficient when the topology changes rapidly reaching robustness and flooding minimization.

***Keywords*:** Ad hoc network, location-based routing protocol, indoor location system.

I. INTRODUCTION

An ad hoc network is a set of wireless mobile nodes that cooperatively form a network without specific administration or configuration. Routing protocols based on topology do not always operate well in all types of configurations in particular when the movement of nodes becomes fast. The rise of technologies of localization, thus offers today new opportunities that can be used by routing protocols to enhance routing performance. Especially, the need for indoor positioning is obviously increasing with the emergence of navigation applications. Many location-based routing protocols are proposed. Most of them use the technology of GPS (Global Positioning System) or GALILEO. But, in indoor environments, GPS cannot constitute alone a solution, because it is rather adapted to the outdoor environments. Thanks to the UNSS (Universal Navigation Satellite System) systems which permit to locate nodes in indoor environments using GPS principles, we address the location-based routing issue in indoor MANETs (Mobile Ad hoc NETwork). We propose two versions of our protocol INGEO. The key idea of our proposals is to user the velocity information in geographic routing. This characteristic enables the obtained information be kept valid much longer than the node's information in GPSR (Greedy Perimeter Stateless Routing) [1] and DREAM [2]. In INGEOv2 (version 2), the ACK packet is sent from destination to source, and serves to confirm the validity of destination's information, because it contains the destination's location information. With this mechanism, the source maintains always the current location of the destination when the session is in progress. As our protocol is conceived for indoor environment, we do not consider the "void zone" problem. This paper is organized as follows. Firstly, in section II, we present review on both indoor location techniques and ad hoc location-based routing protocols. Then, we detail the operation of INGEO in section III. In section IV, we give an analysis of the obtained simulation results. Finally, we conclude the paper in Section V and highlight some future work.

II. RELATED WORK

Indoor location techniques can be classified into three approaches: network-based, handset-based and hydrid positioning. For the first approach, positioning is performed using signals and hardware, such as network-based TOA [3], cell-ID [4] techniques. For the second approach, positioning is done using an independent positioning system, such as A-GNSS (currently known as Assisted GPS or Wireless Assisted GPS) [5,6]. For the last approach, we can apply several independent positioning systems; the simplest implementation of hybrid systems is to combine A-GNSS with Cell-ID. But these indoor location systems are difficult to deploy. An efficient alternate solution to existing indoor location techniques has been developped by [7].Its location method consists of retransmitting GPS signals, which are received outside a building by a GPS repeater, towards a standard GPS receiver located inside. The GPS repeater based-indoor position finding has proven to be feasible in various indoor environments and gives typical one meter accuracy. Furthermore, this technique allows a current GPS receiver to output both location and velocity, as it does outdoors. This system operates thus indifferently outside and inside.

Location-based routing protocols eliminate some of the limitations of the cited topology-based routing approaches by using nodes' location. These protocols use the position of the destination to perform packet forwarding. Since explicit routes are not maintained, location-based routing does scale well even if the network is highly dynamic. This is a major advantage in a MANET network where the topology may change frequently. Many strategies are used to obtain the location of the neighbors, we can find: one-hop, some-for-some, some-for-all, all-for-some or all-for-all broadcast. Furthermore, we can distinguish three main packet-forwarding techniques [8]: greedy packet forwarding, restricted directional flooding and hierarchical routing. The location information is assumed to be available for each node by using GPS or other type of positioning service like GLS. However, obtaining this critical information in indoor environments remains a main issue since such localisation methods are neither simple nor accurate. The recent proposed protocols include LAR [9], DREAM and GPSR, GRA [10] and LABAR [11]. In this context, we propose a reactive location-based routing protcol for the MANET indoor environment taking benefits from the characteristics of the positioning method (velocity, accuracy, simplicity). Our method can also be applied in outdoor environment.

III DESCRIPTION OF INGEO

Our protocol INGEO is composed of three procedures: location management, location discovery and transmission of data packets.

III.1 Location management

Based on the indoor location system [7], each node periodically receives the current location information which is gathered in a location table. In fact, the location system permits to calculate the position's coordinates and speed simultaneously. We assume that the location information of others nodes is also maintained in the location table which includes its spatial coordinates, the speed vector and location updating time. Considering a small density of our expected network, the overhead of maintaining this table is negligible, and the development of a distributed location service is not necessary. The key innovation of our proposition consists of using complete location information of a node including its velocity coordinates

Node's identity	Position	Speed Vector	Time of acquisition
Idx	(X, Y, Z)x	(Vx, Vy, Vz)x	Tx
Idy	(X, Y, Z)y	(Vx, Vy, Vz)y	Ty
Idz	(X, Y, Z)z	(Vx, Vy, Vz)z	Tz

Table 1. Location table

III.2 Location discovery

INGEO applies the flooding approach to discover the nodes' location. When a source does not have the destination's location with which the source is willing to connect, the source propagates a location request packet through the network until it reaches a node who knows the location of the destination (an intermediate node or the destination). The location request packet collects the identity of each node by which the packet passes; it is used for the return of a location reply packet. The node who knows the destination's location generates a location reply packet containing the information of the destination and a path of return which is copied from location request packet. As soon as the source receives a location reply packet, it updates its location table.

III.3 Transmission of data packets

Upon receiving the destination's location, the procedure of data transmission is executed by the source. The source includes the destination's location in the header of each packet, and broadcasts it to its neighbors. A node, receiving data packets, updates the destination's information in the packet header if it possesses more recent destination's information. The node calculates the distance (its distance to the destination and the distance between the previous node and the destination) with the most recent destination's information by applying the following formulas:

$$d_{ID} = \sqrt{(x_D + v_{xD}T - x_C)^2 + (y_D + v_{yD}T - y_C)^2 + (z_D + v_{zD}T - z_C)} \quad (3.1)$$

$$d_{PD} = \sqrt{(x_D + v_{xD}T - x_E)^2 + (y_D + v_{yD}T - y_E)^2 + (z_D + v_{zD}T - z_E)} \quad (3.2)$$

Where d_{ID} is the distance between this node and the destination (see formula 3.1), d_{PD} is the distance between the previous node and the destination (see formula 3.2), T is time interval between the moment when the packet is treated by an intermediate node and the moment when the location information is obtained, (x_D, y_D, z_D) is the destination's position, (v_{xD}, v_{yD},v_{zD}) is the destination's speed, (x_C, y_C, z_C) is the current node's position, and (x_E, y_E, z_E) is the previous node's position. By comparing these two distances, if this node find itself closer to the destination than the previous node, it forwards the packet, if not, it simply drops the packet. In a first step, we only take into account the distance information to choose the routes. In the future work, we will consider quality of links in addition to distance to tackle the high variation of wireless links and to offer more adaptive solution to highly varying ad hoc environments. When the data packet is received by the destination, the latter generates an ACK packet, which is sent to the source following the reverse route. This ACK packet serves to confirm that the destination's position known by the source is correct. The ACK packet should be received by the source within a timeout period, so the source also launches a timer for each data packet. If the source does not receive an ACK packet within a timeout period, it launches a new location discovery procedure.

III.4 The second version INGEOv2

As previously described, INGEO relaunches the location discovery procedure if the source does not receive the ACK packet within a timeout period. But the ACK packet may be lost due to congestion. In this case, the location discovery may produce more congestion. Moreover, this procedure is useless, because the destination's location still remains valid. We propose another version named INGEOv2. Before sending data, the source launches the location discovery procedure. Then, the source starts sending data, and the destination returns an ACK packet for each received data packet. In this ACK packet, the destination puts its current location. If the source can receive at least an ACK packet during a certain interval, the source maintains always the current location of the destination (the source does not need to run again the location discovery procedure). In the extreme case where the source does not receive any ACK packet, the location discovery procedure is relaunched. However, as the destination returns several ACK packets during each interval, the probalility of loss of all these packets should be low. Hence, the second version minimises the number of dropped packets in case of congestions, but extra information is added in the ACK packet.

III.5 Optimization

Globally, INGEO has some interesting properties:

- Robust: packets can reach the destination through several routes. Moreover, thanks to the knowledge of the speed vector and the destination's position, we can know previously displacements of the destination, and send the packets towards the expected direction.
- Loop-free: as each packet propagates from the source to the destination towards a special direction, there is no loop.
- Short delay: since information in the location table can be valid much longer than a route from the source to the destination, location discovery is less frequent than route discovery, as performed in DSR or LAR, i.e. data packets have good chance to be sent immediately. Hence, delay is minimized.

To improve INGEO, we proposed three optimizations. Aiming at benefiting of the forwarding phase, we propose to use the location information embedded in forwarded packets by intermediate nodes. Another optimization consists of improving the location discovery procedure by giving a TTL (Time To Live) to each location request packet. The value of TTL starts with a small value, and the source propagates this packet. If the source cannot receive a response, it increases the value of TTL and propagates it again. Thirdly, in order to improve INGEOv2, the destination does not return an ACK packet for each data packet, but in case of speed changes. With this optimization, the number of ACK packets will consequently decrease. Moreover, inaccuracies in location information due to localisation errors are considered.

IV. PERFORMANCE RESULTS

In this section, we analyze the performance of INGEO (version 1 and version 2). Initially, we compare INGEO with DREAM and LAR, two location-based protocols, and DSR [12] which is a topology-based protocol. Then, we analyze the performance of INGEO in a specified indoor environment. Simulations are carried out with NS2 (network simulator 2) tool. In our study, we consider the constant parameters as shown in the following table.

Timeout for Location request packet	1.2 seconds
Timeout for ACK packet	1.0 seconds
Buffer size	100 packets
Timeout for TAB-LOCA	30 seconds

Table 2. INGEO constants

IV.1 Simulation model

As mentioned in [13], there is a strong relationship between node's speed and pause time. For example, a scenario with fast mobile nodes and long pause times actually produces a more stable network than a scenario with slower mobile nodes and shorter pause times. Therefore, in our simulation, the speed of a node is uniformly distributed in [V_{MIN}, V_{MAX}], where V_{MIN}=average speed-2, V_{MAX}=average speed+2. In the comparison study between INGEO and others routing protocols, we do not limit the simulation parameters to be related only to the indoor environment, i.e. we vary the speed until 20 m/s in order to make a large study since the used localization technique can be used for both indoor and outdoor. We execute 10 simulations for each speed value, with 60 different mobility scenarios. Table 3 lists the used simulation parameters.

Simulation time	250s
Simulation area	600x300 m
Number of nodes	50
Transmission range	100 m
Average neighbors	7.76
Movement model	Random WayPoint
Maximum speed	0-22 m/s
Average speed	0, 3, 5, 10, 15, 20 m/s
Pause time	0
CBR sources	15
Data payload	64 bytes
Packet rate	4 packets/s
Traffic pattern	Peer-to-peer

Table 3. Simulation parameters

IV.2 Performance analysis

In our comparison of INGEO (version 1 and version 2) with LAR, DREAM and DSR, we consider the following performance metrics: delivery ratio which is the ratio of the number of data packets delivered to the destination nodes divided by the number of data packets transmitted by the source nodes, end-to-end delay, protocol overhead which is the number of control packet transmissions for each data packet, and data load which is the number of data packet transmissions for each data packet.

Figure 1 illustrates the data packet delivery ratio versus speed. At speed 0 m/s, the data packet delivery ratio for DSR and LAR is 100%. But for the three other protocols, even if at the speed 0 m/s, there are already lost packets, because geographical routing overloads the network, the loss of packets is due to the limited buffer size and the congestion in the network. As speed increases, the data packet delivery rate of DSR and LAR decreases, especially for DSR, which floods the packets route request each time when the route towards the destination is not valid. Compared to DSR, LAR is able to use destination's location information to find a new route to the destination, so its delivery ratio is higher than DSR. In addition, we observe that the delivery ratio of the three protocols remains almost stable when speed increases. Among these three protocols, INGEOv2 is the best, because, after the discovery of the destination, INGEOv2 rarely executes the location discovery procedure thanks to the reception of ACK packets, so it generates less loss than DREAM and INGEO (version 1).

Figure 2 illustrates the average end-to-end delay as speed increases. The delay depends on two elements: the time needed for waiting the location discovery or the route

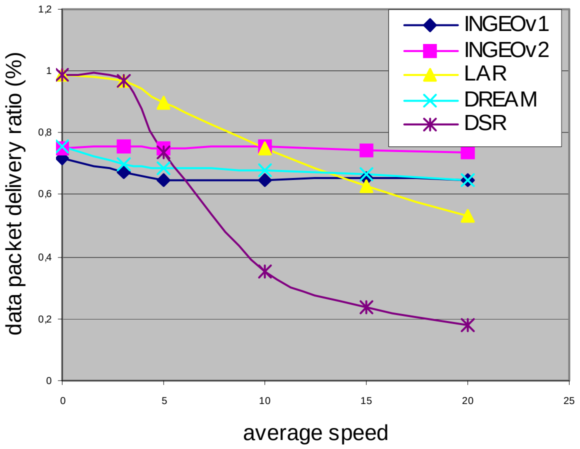

Fig. 1. Data packet delivery ratio vs. speed

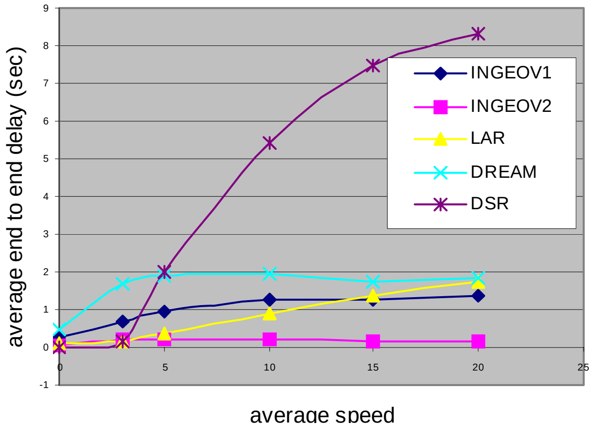

Fig. 2. End-to-end delay vs. speed

discovery procedures, and the transmission time of packet from source to destination, which depends on the load of the network (in our simulation, propagation time is the same). We note that INGEOv2 outperforms the other four protocols, because after the discovery of the location, INGEOv2 always maintains the current position of the destination (as mentioned in Section 3). It sends immediately data packets, without waiting for the discovery of the location. It is also the reason for which the delay of INGEOv2 almost does not change when speed increases. As speed increases, more location requests are needed in INGEO (version 1), thus its end-to-end delay increases according to speed. DREAM's is a proactive protocol; however, its delay is higher than INGEO and LAR. Since a source has a timeout for receiving an ACK of 500 ms, which often expires, so the DREAM recovery procedure (that floods data packets) is often used. In the case of low mobility (average speed<3 m/s), for DSR and LAR, the probability that the route towards the destination remains valid during simulation is high. Moreover, these two protocols have less transmission time (at the speed lower than 3 m/s, they have less load); they have the smallest delay. However, when speed is higher than 3 m/s, the delay of DSR increases largely, because of the congestion of the network and the discovery location procedure delay. Moreover, we notice that DSR is the least efficient.

Figure 3 shows the number of control packets delivered as speed increases. We note, in the case of low mobility (speed lower than 3 m/s), DSR and LAR always offer the best results. In fact, the route discovery procedure is not often launched. Obviously, when speed increases, the frequency of the route discovery procedure increases. Consequently, the overhead also increases, and we see, from speed 7 m/s, the overhead of DSR is the highest. The overhead in INGEOv2 remains almost constant during simulation, because the number of the control packets is composed of the number of the packets transmitted during the location discovery procedure, and the number of ACK packets which corresponds to the number of packets received by the destination (it almost not change at different speeds). Therefore, the number of control packets of INGEOv2 is constant for different speeds. For INGEO (version 1), as the number of location packets and location reply packets increases as speed increases, the overhead increases also with speed. Since DREAM sends the location packets periodically, its overhead remains highest (except DSR) during the simulation.

Figure 4 illustrates the data load of the five protocols as a function of node speed. Obviously, the two routing protocols DSR and LAR, which send packets along a specified route, support much less load than the three protocols (INGEO (version 1 and 2) and DREAM) which route geographically data packets. We note that the number of transmitted packets generated by DREAM is much higher than INGEO (version 1 and 2), but we cannot conclude that INGEO outperforms DREAM, because INGEO broadcast the data packets to neighbors, contrarily to DREAM.

Figure 5 illustrates the total number of transmitted bytes. DSR and LAR always offer the best results. However, with speeds higher than 15 m/s, the delivery ratio of DSR and LAR is the smallest (Figure 1). So the majority of the transmitted bytes are control packets.

In the following, we analyze the performances of INGEOv2 in a specified indoor environment where two parameters (number of nodes and number of connections)

Simulation time	250s
Simulation area	100x50 m
Number of nodes	16, 20, 24, 28, 32, 36, 40
Transmission range	20 m
Movement model	Random WayPoint
Average speed	2, 4, 6, 8, 10 m/s
Pause time	10.0
CBR sources	5
Data payload	64 bytes
Packet rate	4 packets/s
Traffic pattern	Peer-to-peer

Table 4. Indoor simulation parameters

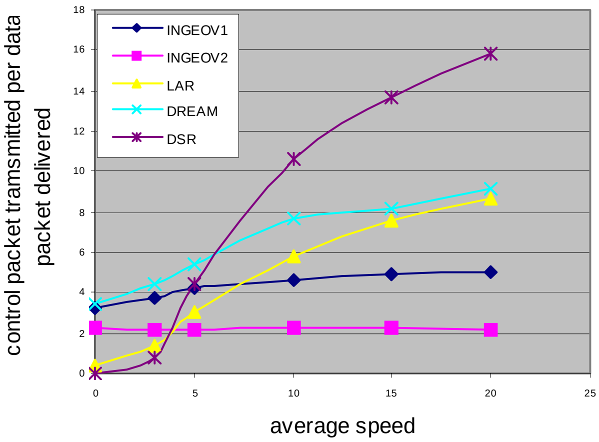

Fig. 3. Control packet overhead vs. speed

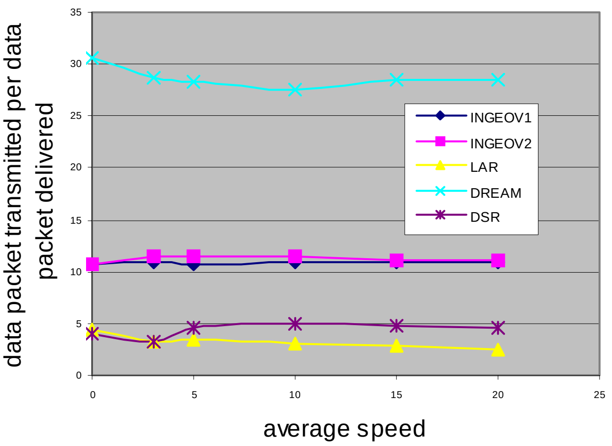

Fig. 4. Data packet load vs. speed

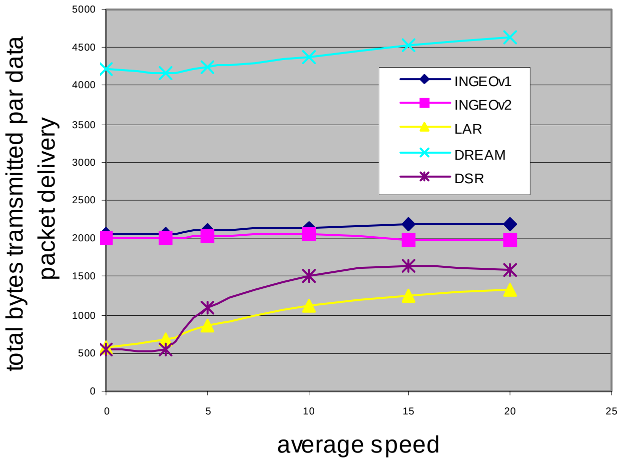

Fig. 5. Total bytes transmitted vs. speed

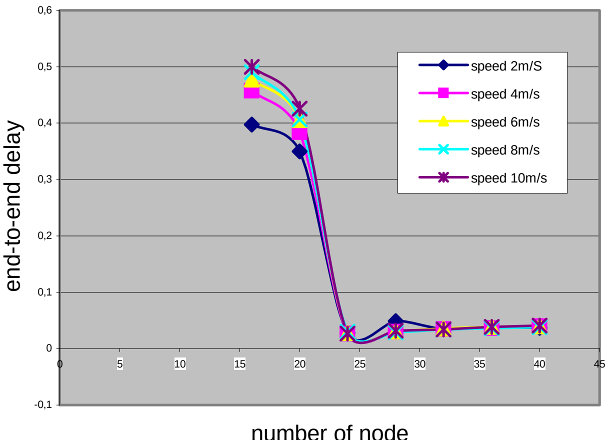

Fig. 6. End-to-end delay vs. number of nodes

vary. Table 4 lists the simulation parameters. We study only the two metrics of delay and delivery ratio as function of speed variation.

From figures 6 and 7, we note that, when the number of nodes is lower than 20, the delay is much more important. Because, in this case, the density of the nodes is very small, some destinations cannot be reached from the source during a certain period; the source must wait to establish a connection. When the number of the nodes is higher than 24, the delay increases slightly as the number of nodes increases, because more nodes take part in the packets' transmission, more the load increases. But the delay remains nearly constant for different speeds; it is the same result that we found previously. As the number of nodes increases, packets have more chance to reach the destination. Therefore, we see that the delivery ratio progressively increases as the number of nodes increases. We also note, on figure 7, when speed increases, that the delivery ratio decreases.

Figure 8 and 9 show the delay and delivery ratio variation as the number of connections increases. Here, we fix the number of nodes at 32, and vary the number of connections (2, 4, 6, 8, 10, 12, 15, 20). We see that delay gradually increases as the number of connections increases. Because the increase of the connection increases the load, which in turn enhances the packets transmission time. When the number of connections is higher than 15 (1/2 of total of a number of nodes), the delay increases considerably, because the network is overloaded. For different speeds, the delay is nearly constant. For delivery ratio, we observe that it decreases progressively as the number of connections increases, because more there are connections, more the load increases, and more there are risks of packets' losses.

V. CONCLUSION

In this paper, we propose a new ad hoc routing protocol named INGEO, which is a reactive location-based routing protocol for MANET. For indoor environments, INGEO benefits of the strength of a new interesting indoor location technique. According to the comparison of INGEO with some others protocols, its efficiency has been shown through several advantages like robustness and the overhead/flooding minimisation. We also propose three optimizations and compare the performances of INGEOv2 when the number of nodes and connections vary. The results showed that, more there are nodes participating to transmit packets, the performance optimized. It is also shown that, when the number of connections is higher than half of the number of nodes, INGEOv2 offers a weaker performance. We notice that INGEO is more powerful than the topology-based protocols if the topology of the

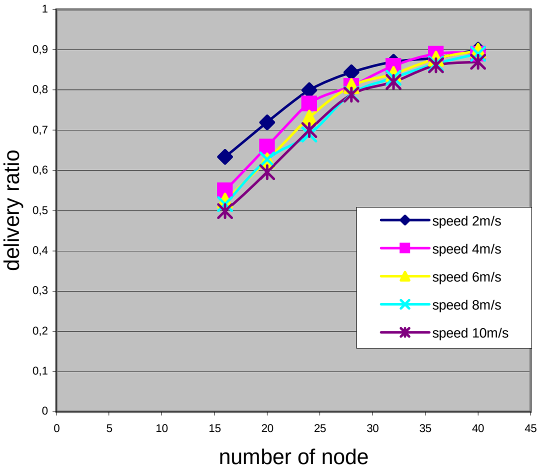

Fig. 7. Delivery ratio vs. number of nodes

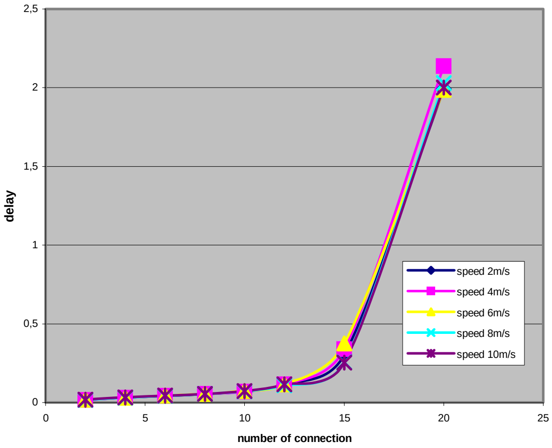

Fig. 8. End-to-end delay vs. number of connexion

network changes quickly, Therefore, for a future work, it will be relevant to design a protocol which can adapt the routing method (geographical routing or traditional routing) according to nodes' mobility. We intend to deeply analyze the behaviour of INGEO by varying other parameters, such as the node's transmission range, the value of timeouts, the buffer's size etc. We also intend to compare its performances to GPSR or other location-based routing protocols, and plan to take into account more realistic mobility models than the random waypoint model.

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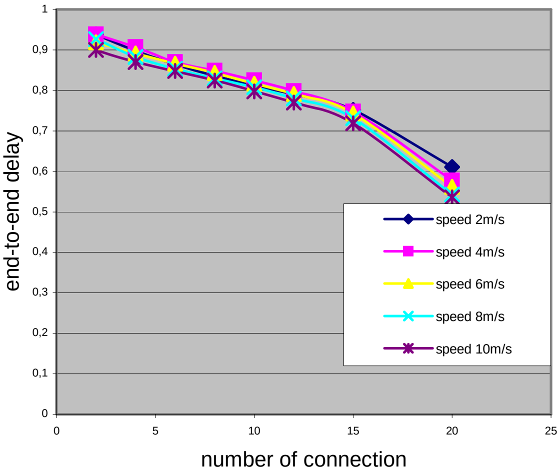

Fig. 9. Delivery ratio vs. number of connexion

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