A Soft Handover for Service Delivery in Intermittently Connected Hybrid Networks

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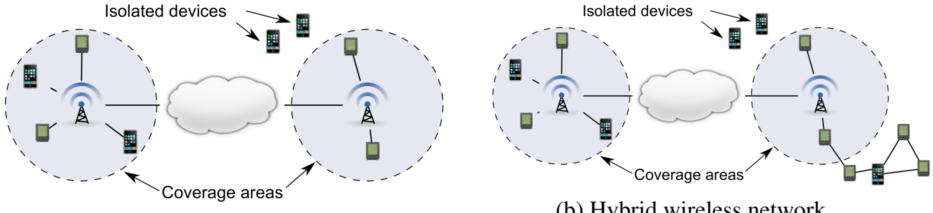
Summary. Today, handheld devices equipped with Wi-Fi interfaces are used intensively by a huge number of people every day. These devices can form intermittently connected mobile ad hoc networks spontaneously. These networks appear as a relevant solution to extend a pre-existing infrastructure-based network composed of several access points in view of providing nomadic people with application services in a wide area. In such hybrid networks, intermittent connections are prevalent, and end-to-end paths between clients and providers cannot be maintained all the time. Thus, the communications must be achieved following a ”store, carry and forward” principle.

In this paper, we present a new soft handover mechanism dedicated to service delivery in such hybrid networks. This handover solution exploits several pieces of information, such as the message propagation time, the path stability, and the mobility degree of intermediate nodes in order to select the most appropriate access point(s) to forward a response to a given mobile client.

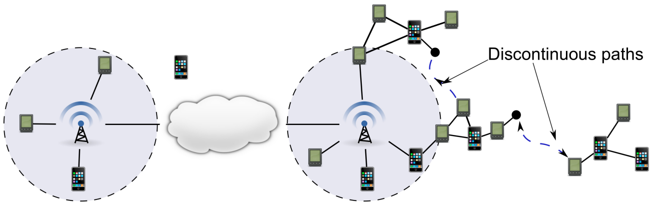
1 Introduction

The recent market researches on mobile computing devices show an incredible penetration of handheld devices equipped with IEEE 802.11 interfaces (e.g., smart-phones, internet tablets) among the population, as well as a significant growth of computing devices embedded in the environment (e.g., Wi-Fi access points, wireless DSL gateways, sensors). These embedded devices are irregularly, and sometimes sparsely, distributed in the environment, and are connected to different infrastructure based networks. In order to access to the Internet or to get some services, the mobile clients must be in the communication range of an access point (see Figure 1a), thus constraining their mobility and reducing the area where a service or an Internet access can be offered. Over the last years, wireless mobile ad hoc networks have been considered in order to provide multi-hop communication between devices, and sometimes to create hybrid networks by extending fixed infrastructures in order to better satisfy the user's needs while using fewer access points to cover a given area. The access points participate in ad hoc communication and provide access to the fixed infrastructure (see Figure 1b). Nevertheless, such hybrid networks still remain rarely used today because their topology suffers from unpredictable changes and connectivity disruptions due to the mobility of the devices and the short communication range of their wireless interfaces. These changes are also the result of the volatility of the mobile terminals that are frequently switched off due to their limited power budget. In these conditions, it is difficult, and even impossible, to maintain an end-to-end path between two devices using legacy MANET (Mobile Ad hoc NETwork) routing protocols.



(a) Simple infrastructure-based wireless network.

(b) Hybrid wireless network.



(c) Multi-hop intermittently connected hybrid wireless networks

Fig. 1: From simple wireless networks to multi-hop intermittently connected hybrid networks.

One of the most interesting evolutions of these hybrid networks is what we call intermittently connected hybrid networks (ICHN) or opportunistic hybrid networks (OHN), whose goal is to enable communications in presence of frequent and unpredictable connectivity disruptions. In such networks, communications rely on the ”store, carry and forward” principle, whose basic idea is to take advantage of device contact opportunities to exchange messages, as well as of the device mobility so as to deliver messages between the different partitions of the network. In ICHN, two devices can communicate even if it does not exist an end-to-end path between them. Such hybrid networks could appear as an opportunity for service providers, such as local authorities, to provide nomadic people with new ubiquitous services, without resorting to any expensive infrastructure, such as those provided by mobile phone operators. The fixed part of these hybrid networks can obviously present various topologies. For instance, the services can be provided by dedicated servers that can be accessed by the mobile devices through the infostations, which act as gateways (see Figure 1c).

In this paper, we focus on the service delivery process in both the mobile and the infrastructure parts of an ICHN, and we present the soft horizontal handover mechanism we have designed and implemented in the infostations in order to improve the service delivery for nomadic people. Unlike the handover mechanism designed for cellular networks, the handover mechanism we propose takes the opportunistic nature of the communications into account. Indeed, the handover decisions are not taken according to the quality of the radio signal between a base station and a mobile client, but according to the quality of the multi-hop discontinuous paths between a client and an infostation. These paths, which can evolve dynamically according to the mobility and the volatility of the devices, are characterized by several properties, such as their stability or their length.

The remainder of this paper is organized as follows. Section 2 presents some related work focusing on handover mechanism as well as on communication and service delivery in opportunistic networks. Section 3 introduces service provision issues in ICHN. Section 4 presents the handover solution we propose to improve service delivery in ICHN. Section 5 shows experimental results we obtained for our handover solution. Section 6 concludes this paper with a discussion on open research directions.

2 Related work

Communications in disconnected or intermittently connected mobile ad hoc networks have been investigated in research works dealing with delay tolerant networking, disruption tolerant networking or opportunistic networking. The solutions presented in these works are generally based on the ”store, carry and forward” principle. Some of them also make assumptions about the device mobility by considering that these equipments are carried by humans that follow social mobility patterns, and that such recurrent patterns can be used to predict the future contacts between the devices and to deliver the messages efficiently with a limited number of copies of these messages. These methods traditionally use a probabilistic metric, often called delivery predictability, that reflects how a neighbor node will be able to deliver a message to its final recipient. Before forwarding (or sending) a message, a mobile host asks its neighbors to compute their own delivery probability for the considered message, and then compares these probabilities and selects the best next hop(s) among them. This estimation can require a 1-hop, and sometimes a 2-hop, network knowledge. In the Context-Aware Routing protocol (CAR) [12], the delivery probabilities are computed using both utility functions and Kalman filter prediction techniques. Propicman [13] also exploits context properties and the probability of nodes to meet the destination, and infers from that the delivery probability, but in a different way. When a node wants to send a message to another one, it sends to its neighbor nodes the pieces of information it knows about the destination. Based on these pieces of information, the neighbor nodes compute their delivery probability and return it. The node that wants to send the message will send this message only on the two-hop route(s) with the highest delivery probability (this probability must further be higher than its own one). Like CAR and Propicman, HiBOp [1] uses context properties in order to compute delivery probabilities, but it uses history information in order to improve the delivery probability instead of making predictions using Kalman filters. In Prophet (Probabilistic Routing Protocol using History of Encounters and Transitivity) [9], when a node wants to send a message to another one, it will look for the neighbor node that has the highest amount of time encountering the destination, meaning that has the highest delivery predictability. Furthermore, this property is transitive in Prophet. These protocols are designed for unicast communications. Thus, they could probably be used for service invocation, which traditionally relies on such a communication paradigm, but not for service discovery, which requires in ICHN an efficient broadcast of service discovery requests and service advertisements. Indeed, in order to avoid the broadcast storm problem and a network congestion, these messages must not be broadcast in a blindly epidemic manner, but instead using dedicated protocols such as OLFServ [8].

Software service provision with delay-tolerant, disruption-tolerant or opportunistic communications has been addressed so far in few research works [10, 7, 14, 2]. Proposals in [10] and [2] focus on service provisioning in opportunistic networks composed solely of mobile nodes. In [10], the authors propose content-based service discovery and invocation solutions in order to exploit the redundancy of the services offered by the mobile devices that can move freely (i.e., no assumptions are made regarding the mobility of the devices). The protocol presented in [2] targets networks relying on social interactions between mobile nodes that act as both clients and providers of services. Due to the volatility and the limited resources of the mobile devices, the number of relevant services that can be offered by these devices is limited in comparison to those that could be offered in hybrid networks. Unlike in [10] and [2], the services considered in [7] are provided by fixed infostations in limited geographical areas. In [7], mobile devices and infostations are aware of their own location. Mobile devices can invoke remote infostations thanks to an opportunistic and location-aware forwarding protocol [8]. In contrast with the environments we consider in this paper, in [7], the infostations were not connected together.

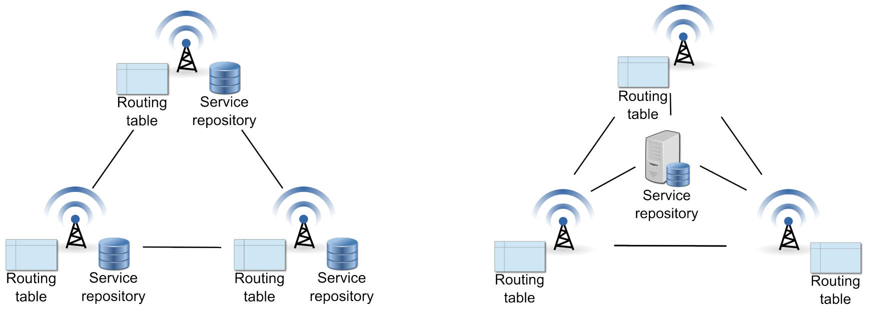
The cooperation between wireless infrastructures and opportunistic networks has been investigated recently in order to enhance the content delivery to mobile clients and to relieve the infrastructure [3, 4, 5, 16, 11]. In [4], Hui et al. show that opportunistic communications can improve the content delivery ratios significantly even in infrastructures with a high access point density. Hui et al. also investigate different strategies to find the subset of mobile devices that will lead to the greatest infection ratio by the end of a message's lifetime [3]. In [5], Ioannidis et al. also focus on the delivery of dynamic content from the infrastructure to mobile subscribers that are expected to replicate it epidemically. They showed that, by supporting such epidemic exchanges and by utilizing the bandwidth of connections between mobile devices, the content providers can support more subscribers with a lower cost. [16] targets the same objective than [3, 4], but it does not focus on social networks and does not assume preexisting knowledge of pairwise contact probabilities. It proposes *Push-and-Track*, a framework that exploits both wide-area wireless networks (e.g., 3G or WiMax) and local-area wireless networks (e.g., Bluetooth or Wi-Fi) in order to achieve guaranteed delivery in an opportunistic network while relieving the infrastructure. In [16], a subset of users will receive the content from the infrastructure and start propagating it epidemically; upon receiving the content, mobile nodes send acknowledgments back to the source, thus allowing it to keep track of the delivered content and assess the opportunity of sending new copies. Service invocation issues in ICHN have been addressed recently with a reactive routing protocol called TAO (Time-Aware Opportunistic Routing Protocol) [11]. In TAO, the routing decisions are taken based on the last date of contact of mobile devices with infostations. Furthermore, TAO implements several optimizations, such as source routing techniques, so as to perform an enhanced service delivery. However, in its current version TAO does not include pieces of information that could help at taking handover decisions.

Several kinds of handover mechanisms and algorithms have been proposed in the past for various types of wireless networks. Vertical handovers [6] and horizontal handovers, which can be qualified as hard or soft handovers, have been proposed. They respectively allow the switching of the ongoing network connection from one wireless interface to another (e.g., handover from an 802.11b network into a GPRS network) and the switching between two networks that use the same network technology and interface. With a hard handover mechanism, a mobile client can be connected with only one access point at the same time, while a soft handover mechanism allows to keep two or more connections with different access points. To the best of our knowledge, none of these handover solutions considers the issues inherent in the ICHNs.

3 Service provision in ICHNs

Three main issues must be overcome in order to efficiently provide nomadic people with services in ICHNs, namely the discovery and the invocation of services using opportunistic communications and the design of a handover mechanism in order to offer a service access continuity to the mobile clients. In the first part of this section, we present different types of infrastructure of infostations, and we show how a handover mechanism should work in ICHNs. In the second part, we describe the service discovery and invocation processes in such networks.

3.1 Handover overview and infostation infrastructures



(a) Architecture example 1.

(b) Architecture example 2.

Fig. 2: Infrastuctures of infostations.

The infrastructure part of an ICHN can present various topologies (mesh, bus, etc.), and the service repositories can be organized in a centralized or distributed manner. For example, the infostations can provide the services themselves and can act as service repositories (see Figure 2a), or can simply act as gateways for other providers that register their services within a centralized repository (see Figure 2b). Other kinds of architectures can obviously be considered. In the remainder of this paper we will assume, without loss of generality, that a service is provided directly by an infostation or via another one.

In order to provide mobile clients with an enhanced service access, the infostations must estimate the ”quality” of the discontinuous/disconnected paths (DPs) between themselves and the clients that require a service, must compare their estimations with those computed by the other infostations, and, if necessary, must update their routing table according to these new estimations.

In the handover solution we have devised, these estimations are obtained by the infostations by processing the pieces of information stored in the service invocation requests they receive, such as the date of emission, the lifetime, the location of the client, etc. The computation algorithm and the properties we consider are detailed in Section 4. This handover solution works as follows: When the infostations receive an invocation request from a new client, or when they compute an estimation that is better than the previous estimation they have in their routing table, they update their routing information and exchange summary vectors with the other infostations in order to allow them to update their own routing table in turn. The infostations are likely to not receive requests from a given client during a long period, because this one has moved away, has became isolated, or has been simply switched off. Thus, the information about this client must no longer be stored in the routing table of the infostations. So as to cope with this issue and to maintain only the recent connections with mobile clients in the tables, we assign a date of computation and a lifetime to each entry. All the infostations thus share the same perception of the infostation(s) that must forward the responses to a given client. In some situations, two (or more) infostations can approximately compute the same estimations for a given client. These infostations are therefore considered as equivalent for the service provision, and all of them should forward the service responses to the client, thus implementing a soft handover mechanism. In the remainder of this section, we describe how this handover solution operates with the service discovery and invocation processes.

3.2 Service discovery

Service provision usually relies on three main operations: the discovery, the selection and the invocation. In a wired network, the service discovery process is often based on a centralized approach: the providers register the services they offer within a registry and the clients can look up available services in this registry, and can obtain a reference to the service they require. In an ICHN, the service discovery process cannot rely on a pure centralized approach since end-to-end routes between the mobile clients and the fixed infostations do not exist permanently. Therefore, each client is responsible for maintaining its own perception of the services offered in the network, and for discovering these services either reactively by processing the unsolicited service advertisements broadcast periodically by service providers and/or proactively by broadcasting service discovery requests in the network and by processing the advertisements returned by providers in response. This discovery process further helps mobile clients to select the paths they must use to forward their requests toward the infostations. Indeed, in the solution we propose the clients can process the pieces of information stored in the service advertisements they receive with an algorithm similar to that implemented in the handover mechanism so as to evaluate the quality of the DPs and to select the best(s) DP(s), and thus to avoid a blindly forwarding process. Such a discovery can be achieved efficiently with OLFServ [8], which performs a geographically-constrained epidemic dissemination of both the service advertisements and service discovery requests.

3.3 Service invocation

A service invocation, during which a given client actually interacts with a provider, is usually performed using a unicast and destination-based communication model. Invoking a service in an ICHN basically consists in forwarding an invocation request toward a given infostation, which in turn will process the request itself if it provides the required service, or will forward the request to the infostation that provides this service. In the solution we advocate, both service invocation messages and service response messages are forwarded using source routing techniques in order to perform an efficient service delivery. Thus, while being forwarded, the messages are updated in order to include the IDs of the intermediate nodes, as well as the other properties that will allow to estimate the quality of the discontinuous path. This list of IDs will then be used to compute the reverse route.

As mentioned previously, when a client requires a service for the first time, it estimates the ”quality” of the DP between itself and an infostation based on the last advertisements it receives. Then, it chooses the best reverse DP(s) that must be followed to forward an invocation. Sometimes several DPs can present approximately the same quality. When these DPs are considered as reliable enough, only one of these candidate paths is selected (the best one). Otherwise, the messages will be forwarded following each distinct candidate path (i.e. following the paths that have no intersection between their list of IDs of intermediate nodes). This DP (or these DPs) will be taken until the source routing fails. When forwarding their responses toward the clients, the infostations use the reverse route defined in the invocation message. When the source routing fails because an intermediate node is no longer reachable, the intermediate node that has detected the failure will execute the same algorithm as the initial client, thus dynamically updating the DP.

4 Handover mechanism for opportunistic computing

Handover decisions and route selections rely on the estimations of the ”quality” of the DPs. In the solution we propose, the DPs are characterized in terms of stability, of distance and of message propagation time. These metrics are defined below.

4.1 Message propagation time

The propagation time is an important metric in the service provision. It reflects the quality of service that is directly perceived by the end-users in terms of reactiveness. The propagation time is computed either by the recipient or the destination of the message (i.e., by a mobile client or an infostation). The propagation time for a message m is given by $pt(m,t) = t - m[de]$, where t is the date of reception of message m, $m[de]$ is the date of emission of message m.

4.2 Distance

We consider two different expressions of the notion of distance: a geographical distance and an estimation of the physical distance based on the number of hops between a source node and an infostation. The geographical distance between a client and an infostation is given by:

$$d'(m) = R \times \arccos(\sin(m[lat]) \times \sin(lat_I) + \cos(m[lat]) \times \cos(lat_I) \times \cos(m[lon] - lon_I))$$

Where, $R = 6378.137m$, and the latitude and the longitude of the infostation and the client are respectively defined in radians by (lat_I, lon_I) and $(m[lat], m[lon])$.

For obvious reasons of energy consumption, nomadic people activate the GPS receiver of their handheld devices only episodically. In order to cope with this issue, we use another estimation of the distance based on the number of hops between a client and an infostation. It must be noticed that, since the clients are mobiles and the links are intermittent, a minimal number of hops between a client and an infostation does not guarantee a minimal geographical distance between these two entities. The estimation we propose therefore combines this number of hops with the message propagation time in order to approximate the maximum distance between these two devices. This approximation is defined as follows:

$$d\text{''}(m) = m[nh] \times CR + s \times (pt(m,t) - m[nh] \times \Delta_{PT})$$

Where $m[nh]$ is the number of hops for message m, Δ_{PT} the delay of an immediate forwarding, CR the Wi-Fi communication range (typically 80 meters), and s the maximum speed of movement of the node (typically 2 meters/seconds for a pedestrian).

The distance $d(m)$ between a mobile client and an infostation is thus given by $d(m) = d'(m)$ if the location properties are available, and is given by $d(m) = d\text{''}(m)$ otherwise.

4.3 Path stability

The stability of a DP is another important metric because it reflects the ability to efficiently forward a message to an infostation or to a mobile client using the source routing technique, and the ability to recover an alternative path if the source routing fails. Consequently, we consider the number of neighbors of the intermediate nodes as an element of stability since it allows to take alternative paths if the source routing fails. Furthermore, this stability depends of several factors, such as the mobility of the intermediate nodes, their power budget, etc. Indeed, the devices are carried and used by humans, and therefore can move freely or following social mobility patterns and can be switched on/off for energy consumption purposes. In the current implementation of our solution, we thus weight each estimation with the distance of a neighbor from the considered intermediate node if the locations, the speeds and the directions are known. Otherwise, we weight these estimations with the contact times that are simply defined by : $c_i = np_i/np$, where np_i is the number of hello packets received from node i (i.e., the number of messages of presence sent by i), and where np is the number of hello packets the node i is expected to have sent since it has appeared in the vicinity of the current node. When the value of this property is equal (or close) to 1, node i is considered as a stable neighbor of the current node. At the opposite, a value close to 0 reflects the sporadic appearance of node i in the neighborhood of the current node. A lifetime is associated with this value so as to consider only the last contacts between two nodes. The path stability estimation obtained locally (i.e., for a given intermediate node) is thus:

$$\sum_{k=0}^{n} ns_k,\, ns_k = \begin{cases} d_k \text{ , } if\ location\ properties\ are\ available \\ c_k \text{ , } otherwise \end{cases}$$

$$and\ d_k = \begin{cases} 1 \text{ , } if\, distanceAt(location_k, s_k, b_k k, 2 \times \Delta_t) \le CR \\ 0 \text{ , } otherwise \end{cases}$$

Where, $location_k$, s_k and b_k are respectively the current location and the speed of movement and the bearing of neighbor node k, Δ_t the delay to forward a message to an infostation from the local node, CR the communication range of the local node, and c_k the contact times of node k. Function $distanceAt()$ returns the distance between the local node and another node at a given time based on the location, the speed and the direction of these two nodes. The path stability value is the minimum of the estimations obtained along the path. It is thus defined as follows:

$$m[pathstatbility] = min(m[path\ stability], new\ estimation)$$

Where $m[pathstability]$ is the stability of the path taken by message m. The function that returns the path stability is thus defined by $s(m) = m[pathstability]$.

4.4 Handover algorithm

The handover algorithm aims at choosing the infostations that must forward the responses to a given client based on the above presented metrics. Similarly, when they have the opportunity to forward their service invocation requests following different DPs, the mobile clients apply a quite similar algorithm than that implemented in the handover mechanism. In the remainder of this section, we focus only on the handover algorithm.

When an infostation receives an invocation request from a client, it estimates the quality of the path taken by the invocation request. Then it checks its routing table for the previous estimations it has for this client. If it has no information about this client, it stores this estimation in its own routing table and sends to the other infostations on a multicast address a summary vector including the modifications it operates on its routing table so that they can propagate these modifications on their own routing table in their turn (see Algorithm 1). If it finds some estimations for the considered client,

Algorithm 1 The section of the algorithm applied upon service invocation reception.

```
Data:
    $\mathscr{R}$: the routing table            $m$: the incoming invocation request
    $I$: the current infostation                $D$: the current date
    $\mathscr{F}$: the estimation function         $\mathscr{V}$: the summary vector
$\mathscr{R} \leftarrow \mathscr{R}$ - {$\mathscr{R}${client=$m$[source] & infostation = $I$}};  T $\leftarrow \mathscr{R}${client=$m$[source]}
$\mathscr{E} \leftarrow \mathscr{F}(m)$
if (T = Ø) then
  $\mathscr{R} \leftarrow \mathscr{R} \cup$ {$m$[source],$I$,$D$,$\mathscr{E}$}  ;  $\mathscr{V} \leftarrow$ {add,{$m$[source],$I$,$D$,$\mathscr{E}$}}  ;  send $\mathscr{V}$
else
  if ($\mathscr{E} \geq$ max(T[estimation]) then
    if ($\mathscr{E} \geq \Gamma_{\mathscr{E}}$) then
      $\mathscr{R} \leftarrow \mathscr{R} \cup$ {$m$[source],$I$,$D$,$\mathscr{E}$} - T
      for all k $\in$ T do
        $\mathscr{V} \leftarrow \mathscr{V} \cup$ {remove,k}
      end for
      $\mathscr{V} \leftarrow \mathscr{V} \cup$ {add,{$m$[source],$I$,$D$,$\mathscr{E}$}}  ;  send $\mathscr{V}$
    else
      for all k $\in$ T do
        if (k[estimation] + $\Delta_{\mathscr{E}} < \mathscr{E}$) then
          $\mathscr{R} \leftarrow \mathscr{R}$ - {k}  ;  $\mathscr{V} \leftarrow \mathscr{V} \cup$ {remove,k}
        end if
      end for
      $\mathscr{V} \leftarrow \mathscr{V} \cup$ {add,{$m$[source],$I$,$D$,$\mathscr{E}$}}  ;  send $\mathscr{V}$
    end if
  else
    if ($\mathscr{E}$ > max(T[estimation]) - $\Delta_{\mathscr{E}}$) then
      $\mathscr{R} \leftarrow \mathscr{R} \cup$ {$m$[source],$I$,$D$,$\mathscr{E}$}  ;  $\mathscr{V} \leftarrow \mathscr{V} \cup$ {add,{$m$[source],$I$,$D$,$\mathscr{E}$}}  ;  send $\mathscr{V}$
    end if
  end if
end if
```

the infostation checks if the new estimation is better than the previous ones. If so, it checks again if this estimation is greater than $\Gamma_{\mathscr{E}}$. If so, it removes the older estimations and only keeps the new one. $\Gamma_{\mathscr{E}}$ is a parameter of the algorithm. When an estimation is greater than $\Gamma_{\mathscr{E}}$, the path is considered as reliable and consequently it is not relevant to forward a message from two distinct infostations. If the new estimation is less than $\Gamma_{\mathscr{E}}$ and better than the previous ones, the infostation keeps only the better estimations that are considered as equivalent (i.e. the estimations whose gap with the better estimation is less than $\Delta_{\mathscr{E}}$). A summary vector is sent to the other infostations in order to propagate the modifications.

When they receive a summary vector, the infostation execute the simple algorithm 2, which consists in adding, removing or updating lines in the routing table.

$$\mathscr{F}(m) = \alpha \times \frac{1}{pt(m,t)} \times s(m) \times \frac{1}{m[number of hops]} \times \frac{1}{d(m)}$$

The estimation of the "quality" of the discontinuous paths is computed using the function defined above. This function aims at privileging the paths that offer a good propagation time and stability, as well as the infostations closer to the client. α is a parameter of the function that allows to obtain results greater than 1 (typically α can be equal to 1000).

Algorithm 2 The section of the algorithm applied upon summary vector reception.

```
Data:
    $\mathscr{R}$: the routing table            $m$: the incoming invocation request
    $I$: the current infostation                $D$: the current date
    $\mathscr{F}$: the estimation function      $\mathscr{V}$: the summary vector
for all k $\in \mathscr{V}$ do
    if k[action] = remove then
        $\mathscr{R} \leftarrow \mathscr{R}$ - {k}
    end if
    if k[action] = add then
        $\mathscr{R} \leftarrow \mathscr{R} \cup \{k\}$
    end if
end for
```

5 Case study

In this section, we present the simulation results we have obtained for the handover mechanism described in previous sections, and we analyze the impact of this mechanism on the service delivery from the client point of view. The simulations have been performed on the OMNeT++ network simulator.

5.1 Environment

The environment we consider in these simulations is a square area of 1 km^2 in which we have deployed 3 infostations. These infostations are connected together, and are separated from each other of 400 m. Each of them provides a specific service. These services are announced periodically (every 5 minutes) by all the infostations. They can be discovered and invoked by pedestrians that move in this area using their handheld devices. In these simulations, we consider two populations of pedestrians: the pedestrians that move following a random way point mobility model, and the pedestrians that move following predefined paths and that can exhibit their location. These pedestrians move at a speed between 0.5 and 2 m/s. In our simulations, 30 % of the mobile devices act as clients of the above-mentioned services, whereas the others only act as intermediate nodes. After discovering the services they are looking for, the clients invoke these services every 3 minutes. They sent a maximum of 10 requests during the simulations. In our experiments, we have assigned to all the messages a lifetime of 10 minutes and a maximum number of hops of 10. The communication range of both mobile devices and infostations varies from 60 to 80 m. In our simulations, we have considered successively 50, 100, 200 and 300 pedestrians. All these parameters are defined so as to reflect as well as possible the behavior of humans that use their mobile phone when they are strolling in a city.

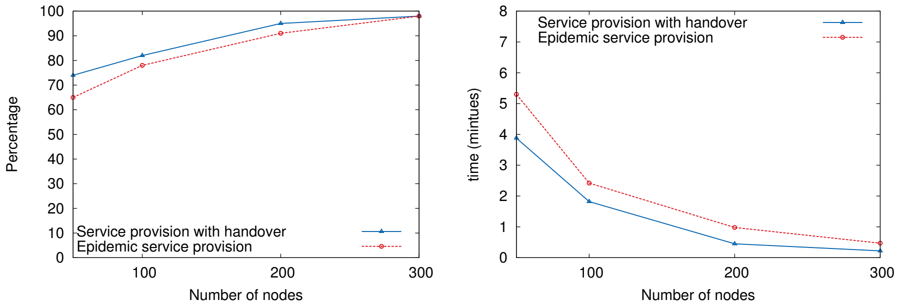
5.2 Simulation results

The objective of these experiments is to measure the impact of our handover solution on the service delivery in various configurations. For that, we focus especially on two values that reflect the quality of service that is perceived by the end-users (the ratio and delay of service delivery), as well as on a value that shows the efficiency of the solution (the number of messages that are sent by all the nodes in the network throughout the whole simulation period). The delivery ratio is the percentage of successful service invocation (i.e., the number of invocations for which a client node receives their response from an infostation), while the service delivery delay is the time needed to forward an invocation message toward the appropriate infostation, as well as to forward the response to the client. We compare the performance of our solution with the Epidemic Routing protocol [15]. In epidemic routing, messages are flooded in the network and stored by all available neighbor nodes as a result of summary vector exchanges, thus maximizing the message delivery rate and minimizing message propagation latency. The first copy of a given service invocation request received by an infostation (or the first copy a given service response received by a client) has therefore followed the path that offers the shortest delivery delay. Moreover, since the responses are disseminated by all the nodes, including the infostations, no handover mechanism is required with this protocol. In this context, the epidemic routing protocol appears as a good candidate to evaluate the efficiency of our solution, even if no precautions are taken in this protocol to limit the number of messages that are disseminated.

Figures 3a, 3b and 3c present the simulation results we have obtained. One can observe that our solution offers a better service delivery in terms of ratio and delays than the epidemic routing protocol, while reducing drastically the number of messages that are forwarded in the network, especially when the number of nodes increases. The delivery delays and service delivery ratios are often better with our proposal because the messages are forwarded using source routing techniques coupled with the handover mechanism resulting in the intervention of the infostation closest to the client, while with the epidemic routing protocol the messages are forwarded after the summary vector exchanges. Due to this short additional latency in the message forwarding, some communication disruptions can occur in certain situations, thus reducing the opportunities to forward the messages. This difference is more observable when the number of devices is low because it is more difficult to find another intermediate node. Furthermore, when the number of nodes increases in the network, the service delivery ratio increases while the service delivery delay decreases. Indeed, as we notice, when having few nodes in the network, the satisfaction ratio of both protocols is almost the same. This observation is coherent with what is expected, because more good carriers can be found among a large set of neighbors, thus reducing the number of disruptions and the disconnection times in the routes.

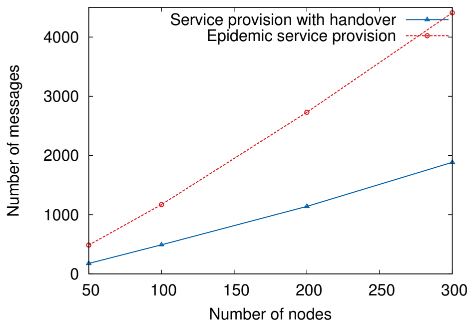
6 Conclusion

In this paper, we have presented a new soft handover solution suited for the service provision in intermittently connected hybrid networks. This solution provides nomadic people with an enhanced service access by selecting the most appropriate discontinuous path(s) between the clients and the infostations. The paths are characterized by



(a) Service delivery ratio.

(b) Service delivery delay.



(c) Network load.

Fig. 3: Simulation results.

three metrics, namely their stability, the propagation time they offer and their length. Furthermore, both the mobility and the number of neighbors of intermediate nodes are taken into account in the stability estimation.

In the future, we plan to consider new kinds of properties such as the power budget of the mobile devices. Finally, we wish to improve our handover solution by considering the successive contacts of a mobile device with infostations, so as to predict its destination without location information and thus its next contact with an infostation. Consequently, allowing us to forward the responses in advance through this infostation.

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