Gateway Discovery and Selection in Mobile Hotspots

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Abstract

Gaining IP connectivity in mobile hotspots (e.g. public transport vehicles) through on-board local area networks and mobile gateways has recently attracted strong commercial and research interests. In this paper we propose a multi-dimensional protocol to support the process of gateway discovery in mobile hotspots, and to help in selecting the best path able to satisfy the user's requirements and to guarantee a target end-to-end service quality. Our proposal is based on highly popular and almost standard protocols, such as SDPng for session description and AODV for route discovery.

1 Introduction

A mobile hotspot can be seen as an entire network, moving as a unit, and gaining connectivity to the Internet via one or more *gateways*. To gain network connectivity in mobile hotspots, such as public transport vehicles, through on-board local area networks and mobile gateways is becoming an increasingly popular area of research and development [1, 2].

Passengers in mobile hotspots are usually connected to an high-speed on-board local area network, which is in turn connected to the Internet via multiple wireless access technologies (e.g., GPRS, UMTS, 802.11, etc.) through a multiplicity of wireless service providers. This "multi-homing" technique has been already proposed in many architectures [3, 4] as a means to increase the aggregate bandwidth for the on-board network; to increase resilience to network disruptions; and to provide a wide range of Internet services to the passengers [5].

Given the advantages of multi-homing in mobile hotspots, a critical challenge is to decide on how to distribute the passengers' data traffic among the available network connections i.e. among the available gateways; which may change frequently as the hotspot moves to its destination.

Our reference scenario is illustrated in Fig. 1. It extends the mobile hotspot model to a wider scenario in which more mobile hotspots, e.g. public transport vehicles, travel along the same road, while the user terminals on board the vehicles can benefit of the presence of one or multiple gateways in their radio proximity, which can be used to connect to multiple different access technologies provided by either the same or different service providers. In other words, users in a mobile hotspot can gain wireless connectivity through one of the on board gateways, or one of the gateways in different vehicles travelling in their proximity, or even through fixed gateways available in the vehicle's neighborhood. Connection to the gateway could be obviously intermittent, because as the vehicle travels, it will experience coverage and resource variations, which affects the choice of the gateway.

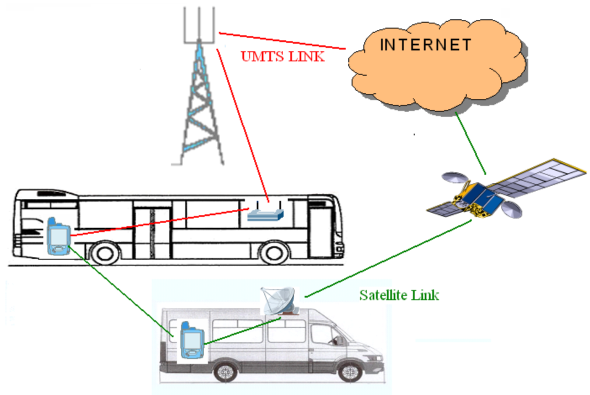

Figure 1. Example of an ad hoc network between mobile hotspots in public transport vehicles

Users board the vehicle, indicate their service preferences, discover available gateways, and select the best gateway for network connectivity and service provisioning. Our focus is on deploying a protocol for gateway discovery and multihop route set up in the ad hoc network among the public transport vehicles. The gateway and path selection is a "multi-dimensional" problem based on service requirements, network type and resource availability, and other high layer parameters such as hotspot and telecomm provider, billing, security, and so on. Higher layer parameters can be requested, as long as they can be described in definite terms that are interpreted the same way by any candidate gateway that can provide the service. In our approach we combine functionality of a well known protocol to describe multimedia sessions characteristics such as SDPng (Session Description Protocol Next Generation) [6], and a highly popular routing protocol in ad hoc networks, that is Ad hoc On-Demand Distance Vector routing (AODV) [7], and its extension to provide quality of service support and Internet gateway discovery [8].

2 Related Work

The issue of gateway discovering has been widely addressed in literature following two main approaches. The first one - which we call *Application Level Approach* - considers the process of gateway discovery as a particular case of service discovery. According to this approach an Internet Gateway is a host providing connectivity service. The other approach - which we call *Network Level Approach* - considers the problem of Gateway discovering as an extension of the routing process.

As far as the *Application Level Approach* is concerned, there is a large plethora of service discovery protocols which can be deployed, the most popular are Service Location Protocol (SLP), Service Discovery Protocol (SDP), Jini, Salutation, Universal Plug and Play (UPnP) [9]. Unfortunately all these protocols, with the exception of UPnP and SDP, have been devised for wired networks and are not intended for use in a wireless environment; furthermore most of them carry out their task using centralized directories. These features make them unsuitable for the use in a highly dynamic environment such as an ad hoc network, which is characterized by sudden changes in topology that cannot be easily managed in a centralized manner.

Within the context of the *Application Level Approach*, many authors have made proposals to select the best service provider among those available in the neighborhood of a requesting station. In [10] the authors propose an extension to the service description in the SLP framework which allows a user to rate available services. This feature is obtained by addition of some *context* attributes, i.e. a high level description of the service, which are evaluated by each user who can assign different weights to different attributes. Given the advantages of allowing each user to define a set of weights according to his/her exigencies, this proposal does not take into account the low level characteristics (such as the available bit rate and the latency) of the path supporting the communication from the user to the service provider. As it can be easily argued, these characteristics are at least as important as the high level ones, especially when the service to be provided is the network connectivity. In [11] the authors propose to partition the network in domains, within each domain a directory server maintains the information about the available services and constantly monitors and probes the network to provide quality of service (QoS) related information allowing to select appropriate service providers. The QoS parameters taken into account are both application level ones (such as CPU usage of the service provider) and network level ones (such as path latency and available throughput). However, such a proactive approach appears to be inappropriate to be used in ad hoc networks because it requires a considerable consumption of resources and it heavily relays on directory servers. In [12] the authors propose to use a location aware routing protocol which subdivides the network in clusters, and within each cluster a router is responsible for communications. The routers interconnecting the clusters can also be used as directory servers for service discovery. This proposal also comprises a ranking algorithm for service selection. In [13] the authors consider the case in which vehicular users are connected one another in an ad hoc configuration and to the Internet through gateways positioned along the road. They propose a service discovery protocol specifically tailored for this scenario, which tries to minimize the number of times a user changes the gateway used for forwarding its traffic. The proposed protocol takes into account the reciprocal position of gateways and vehicles, and the speed and direction of these latter ones. The selection process is accomplished through a fuzzy system.

Within the *Network Level Approach* a good reference work is presented in [8]. In this work the AODV protocol [7] has been extended to provide connection of the ad hoc network to the Internet. The extended protocol has been named AODV+. More specifically, with respect to the standard AODV protocol, a new control message, called RREP_I, is sent back by gateways after receiving a route request (RREQ) message, i.e. when a new flow is generated. The source node gets RREP_I messages from each gateway. If after a RREQ no standard reply message is received (i.e. the destination may be not reached through the ad hoc network) but some RREP_I messages are received, the source node uses them to select the shortest path toward a gateway.

In [14] service discovery is also integrated into AODV such that services are specified and discovered in parallel with route discovery. In simpler terms, the desired IP address of the destination is replaced by the desired service characteristics of a service provider. In [15] the authors investigate the issue of providing QoS to a user accessing the Internet through an ad hoc connection; they highlight that the QoS level perceived by the mobile user is the result of (i) the

QoS along the path to the gateway; (ii) the QoS offered by the gateway itself; and (iii) the QoS offered by the fixed infrastructure. Therefore, they argue that a gateway discovery protocol, which deals with QoS support, should take into account a gateway selection algorithm, a QoS routing protocol, and a signaling scheme which allows to reserve resources in the fixed part of the network. However in [15] the authors concentrate mainly on QoS routing leaving the other topics they have highlighted for further works.

3 Selecting the best path toward external networks

The approach we follow in this paper tries to combine the *Network Level Approach*, which allows to take into account the QoS characteristics of the route connecting the user to the gateway, and the *Application Level Approach* which allows to find a matching between the user requirements and the high-level features of the gateway.

According to our idea, each time a new flow is originated by a user within one of the transport vehicles in Fig. 1 and is addressed to an external host, it must be routed to the "best" gateway through an ad hoc wireless path. The ad hoc path may only involve the high-speed on-board local area network from the user terminal to one of the mobile gateways available on board the vehicle, or it can benefit of the presence of other (mobile or fixed) gateways available outside the vehicle and located in the radio proximity of the user terminal.

The "best" gateway is the one (i) that provides the type of service requested by the user in terms of high-level descriptive parameters, and (ii) that, in the same time, matches the QoS requirements along the end-to-end path from the user through the selected gateway to the external network. For this reason, we split the problem into two distinct, though correlated, issues: (i) establishing QoS-aware paths within the mobile hotspots environment towards available gateways; and (ii) discovering the preferred gateway, i.e. the one that matches user/applications' requirements with the availability of resources in external networks. In the next paragraphs we will describe the procedures used to accomplish these tasks.

3.1 QoS-aware routing toward a gateway in the mobile hotspot

Every new flow originated by a user terminal within the mobile hotspot and addressed to an external host must first find a gateway providing network connectivity. When the flow carries multimedia traffic, QoS constraints are also imposed on the multihop path to the gateway. We choose AODV [7] as a reference routing protocol and consider its extensions to provide Internet connectivity [8] and to cope with QoS sensitive flows [14]. As already said in the Related Work section, the AODV extension to provide Internet gateway discovery, named AODV+ [8], uses a new control message, called RREP_I, which is sent back by a gateway after receiving a route request (RREQ) for a path to an external node. When more RREP_I messages are received, the source node selects the path toward the nearest gateway. The QoS extension to AODV [14], that we call AODV-QoS, aims to match the user's expectations in terms of both end-to-end delay and minimum bit-rate. If a node cannot satisfy the QoS constraint indicated in the QoS extension of RREQ packets, it does not forward the route discovery message. With reference to the delay control, when a path discovery procedure is started, the end-to-end amount of time allotted to a flow is decreased hop-by-hop with the time already spent in intermediate nodes along the path. A QoS path is not established if the residual time reaches zero before arriving at destination. Besides the delay bound, also a minimum bit-rate can be guaranteed by every node along the path in order to supply the desired capacity between the connection endpoints.

In our scenario, which considers flows directed to nodes in external networks, we use the QoS extension of AODV to find a suitable path to the available gateways, which provide the Internet connectivity for the mobile hotspot. Thus, we combine the use of both AODV+ and AODV-QoS. The end-to-end delay is constituted by the sum of two contributions: the latency required (i) to reach the selected gateway, and (ii) to get to destination through the external network. We assume that gateways can get estimates of the delay contribution in the external network, as explained in the next section, so they can determine the residual latency allowed in the mobile hotspot segment. Clearly, a path is not established if the residual latency for the hotspot is exceeded. As for the bit rate, we dynamically assess the achievable throughput at each hop by means of an exponential average of the throughput values experienced by past transmissions on that hop, as explained in [16].

The main novelty in our approach is that when a RREQ message reaches a gateway, it starts a two-phase control pertaining not only QoS parameters (i.e. delay and bit rate) but also some *high-layer* constraints. While the former phase can be carried out at the network layer by the routing protocol itself, the latter phase requires the use of a higher layer protocol to describe other user's exigencies. In other words, the network layer triggers the execution of a higher layer control procedure. The next section will give more details on this phase. Only if both control phases are successful, and an end-to-end path can be established which satisfies all the user's requirements, the gateway sends back a RREP_I message, directed to the source node. Finally, the source node, which receives RREP_I messages from multiple gateways that are able to satisfy the requirements, can select the best candidate gateway, for example the nearest one, and start transmitting data.

3.2 The Gateway selection procedure

Establishing multimedia sessions is normally accomplished through specific protocols, like Session Initiation Protocol (SIP) [17] or H323 [18], which are often accompanied by suitable descriptions of the session characteristics. Session Description Protocol Next Generation [6] is currently under design as an extensible framework, based on XML (Extensible Markup Language), aiming to describe multimedia sessions and to negotiate capabilities of the involved end hosts. Beyond mandatory sections pertaining the involved multimedia streams, an SDPng description can provide an optional section, called *Session Information*, which contains data about the session.
Keeping in mind our reference scenario, we suggest to enhance the SDPng description coming from an ad hoc node which is originating a multimedia session, with further *Session Information*, pertaining high layer preferences of the user/application. We consider a simple profile describing some high layer parameters which directly impact on the choice of an external network toward the Internet. Among these, we enumerate

- *service providers* the user can have subscribed an agreement with;
- *security level* that represents the capability of the external network to provide access control and/or data confidentiality;
- *cost* the user is willing to pay for the required service, expressed through a suitable currency.

In listing 1 we report as example an excerpt of SDPng description, more specifically its *Session Information* section, contained in the *info* element. We introduce new XML elements, within the *part* element, in order to specify some of the aforementioned parameters. Before a QoS flow gets started, a session initiation message, e.g. a SIP INVITE, is issued towards the destination node, carrying an SDPng description. Consequently, a route discovery procedure is triggered within the mobile hotspot. We propose to embed the session initiation message as the payload of the first exchanged AODV message, i.e. the RREQ message. Gateways will act as SDPng proxies, processing SDPng messages, and verifying the availability of the requested parameters in external networks together with the flow QoS constraints reported in RREQ header. Subsequently, if all the aforementioned conditions can be met, gateways will relay the session initiation exchange on external networks, filtering out the *Session Information* section, and reply to the ad hoc routing discovery procedure. Otherwise, they will

Listing 1. example of SDPng Description

```
<?xml version="1.0"?>
<sdpng xmlns="http://www.iana.org/sdpng"
 xmlns:sdpng="http://www.iana.org/sdpng">
   [...]
   <info>
     <part type="Custom">
   <provider num="1">MyFirstProvider.com
     </provider>
   <provider num="2">MySecondProvider.com
     </provider>
   <security>3</security>
   <cost>30</cost>
     </part>
   </info>
</sdpng>
```

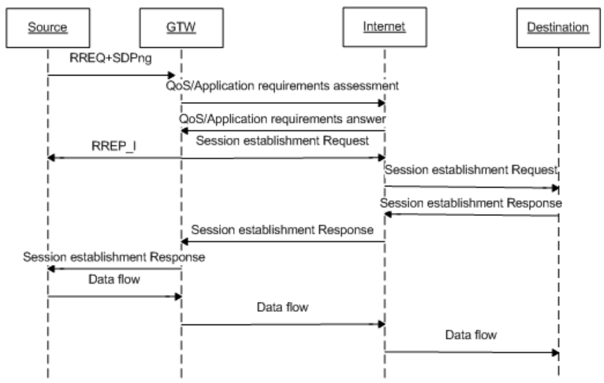

Figure 2. Signaling exchange for successful gateway selection

drop request messages, thus rejecting both session initiation and route discovery. Gateway operation is shown in Fig. 2, where we suppose to use a single handshake scheme for session establishment, as foreseen for example by SIP [17]. After receiving an SDPng description, every gateway is required to assess two disjoint sets of requirements:

- QoS constraints along the end-to-end path towards the destination host, which can be verified and set-up through network-specific procedures, e.g. PDP (Packet Data Protocol) context activation in UMTS (Universal Mobile Telecommunications Systems) networks, or general purpose QoS protocols, e.g. IP Differentiated Services, etc. Furthermore, the gateway will evaluate the actual delay guaranteed by its external network to reach the destination node. Thus, it will be able to assign a maximum tolerated delay in the hotspot segment, obtained just subtracting the contribution of external delay by the total end-to-end delay budget requested by the application. Gateway will break routes in the mobile hotspot if this bound is not satisfied during the session lifetime.

- Application/user preferences which are verified locally or asking to suitable network services, e.g. 3G location registers. If, for example, a gateway behaves as a Point of Presence for a service provider it must verify if a roaming agreement is available between its own service provider and the ones being requested by the user.

At present, we consider a strict matching between resources requested by multimedia sessions and those available. That is, a gateway answers to a request only if all of the session requirements are satisfied. When in presence of several gateways in the mobile hotspot area, it can happen that more than one gateway satisfies the requests from the same flow. In such a case, the source node will select the shortest route.

4 Comparing legacy and proposed approaches

To assess the effectiveness of the proposed approach we simulated the network scenario depicted in Fig.3 using the Network Simulator 2, ns2, (available at http://www.isi.edu/nsnam/ns/). We simulated a 1000m-long segment of a highway, where buses and cars move at a random speed, ranging between fixed bounds. In order to appropriately model this scenario we consider two levels of mobility. The first is the mobility of the users within the public transport vehicle (e.g., passengers in a bus), the second level concerns the relative movements between vehicles on the road. The local movements of passengers within a vehicle are modelled according to the Reference Point Group Mobility (RPGM) model [19]. According to this model, users are divided into groups; each group has a logical center (a group *leader*) that determines the group's motion behavior. Each member of the group is uniformly distributed in the neighborhood of the group leader.
To model the movement of a transport vehicle along the road, each group is forced to move according to the so-called Freeway Model (FW) [20]. According to this model, a mobile node is restricted to move along a straight line, which represents a highway lane. The speed of each node may randomly vary within an interval around an average value.
We simulated ten vehicles, e.g. buses or cars, moving along the highway and carrying, on average, three communicating users. Only five of the ten vehicles are equipped with an on board gateway which offers network connectivity. Characteristics of the simulated gateways are summarized in Table

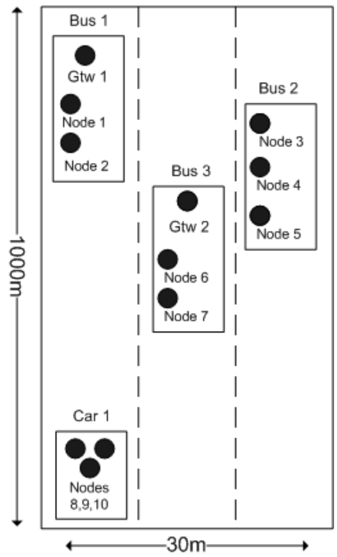

Figure 3. Reference simulation scenario

1.
The duration of each simulation run is 600s; simulations are repeated 20 times varying the mobility patterns, with vehicles moving at a random relative speed between 1 and 10 m/s. Results are reported with a 95% confidence interval of the averaged measures. Table 1 contains the gateways' characteristics: technology which provides gateways with network connectivity; QoS parameters, in terms of average bit-rate and delay, that can be achieved in the external network toward the destination node; high layer capabilities they can provide to customers, according to the vocabulary exposed in the previous section. Looking at these values, we assign a higher cost to the satellite gateway and a different set of supported network providers for each gateway; furthermore, in this example configuration, we do not differentiate the security level the gateways are able to provide. For the sake of simplicity, at this stage we suppose to model the QoS performance achievable in external networks with fixed values. This assumption, though not realistic, allows focusing on the main issue of the proposed algorithm, that is choosing the best available gateway between the mobile hotspot and the external world.

We observe two flows, originated by a user placed in a vehicle and directed outward, whose characteristics model two multimedia sessions with different requirements: the first, a 64kb/s Constant Bit Rate (CBR) flow, represents a voice call, with low tolerated end-to-end delay and throughput; the second, a 192kb/s CBR flow, stands for a video streaming session, asking for high bit-rate, but with not stringent delay requirements. User/applications and QoS requirements for the two sessions are reported in Table 2. In

Gateway	Connected external network	QoS performance	Cost	Provider	Security Level
Gtw 1	Satellite	1.5Mb/s, 0.3s	10	Agreements with all providers	1
Gtw 2	3G cellular UMTS	128kb/s, 0.05s	3	prov1.com, prov2.com	1
Gtw 3	3G cellular UMTS	128kb/s, 0.05s	3	prov2.com	1
Gtw 4,5	2.5G cellular GPRS	56kb/s, 0.1s	2	Agreements with all providers	1

Table 1. Simulated Gateways Characteristics

Flow	Maximum end-to-end delay	Minimum bit-rate	Required provider	Maximum cost	Security Level
voice	0.125s	32kb/s	prov1.com	3	1
video	0.5s	192kb/s	prov2.com	10	1

Table 2. Requirements of the two multimedia flows

our simulations, ad hoc nodes in the hotspot implement the recently released IEEE 802.11e standard [21], which manages QoS control directly at the MAC layer. We consider the distributed QoS control strategy, called Enhanced Distributed Control Access (EDCA), that allows to differentiate QoS performance of different traffic classes through prioritization of MAC frames in four queues: delay sensitive voice traffic is serviced by the highest priority queue, the one with priority 0; video traffic is passed to the queue with priority 1; flows marked as best effort and background are managed, respectively, by queues with priority 2 and 3 (see Table 3).

We show performance results obtained using the legacy gateway discovery approach, i.e. AODV+, and the one proposed in this paper. Fig. 4 shows the throughput obtained by voice and video flows under different mobility conditions. We observe that our approach on gateway selection achieves higher throughput, close to the application requirements, for both voice and video flows. This result can be explained observing Fig. 5 and 6, where the percentage of packets being serviced by each gateway is reported for 1 m/s mobility scenario. We notice that, as we could expect looking at flows' constraints and gateway characteristics, our algorithm forces the voice flow to search paths through *gateway 2*, the only one that can satisfy its requirements, while the video flow uses only *gateway 1*. Clearly, this choice enables better performance, since other gateways can not offer the guarantees requested by the considered multimedia sessions. Differently, the legacy approach does not differentiate among flows' and gateways' characteristics, so it distributes its traffic among the available gateways, without any reference to sessions requirements. These advantages still hold in higher mobility scenarios.

Similar reasonings hold about the end-to-end delay experienced by the flows. Fig. 7 shows that our approach allows to get session's requirements in all of the considered scenarios. Differently, the legacy solution brings to unacceptably bad results for both flows, since it is unaware of the sessions requirements and, thus, selects gateways that are unable to provide flows with sufficient resources. This result is further strengthened by Fig. 8 that shows the goodput of each flow, i.e. data packets that have reached destinations within the committed end-to-end delay bounds. Comparing Fig. 8 with Fig. 4, we notice that our approach allows to achieve a goodput almost equal to the throughput, differently from legacy, which instead has to drop much of the incoming data at the destination node, due to excessive delay.

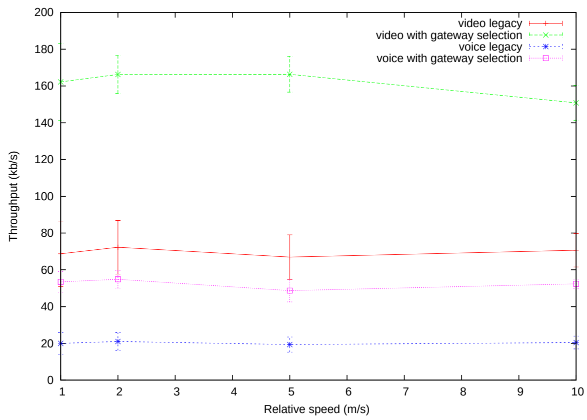

Figure 4. Throughput obtained by voice and video flows under different mobility scenarios

5 Conclusions

In this paper we focused on an extended mobile hotspot scenario where multiple public transport vehicles travel along the same road. The user terminals on board the vehicles can benefit of the presence of one or multiple gateways in their radio proximity, which can be used to connect to multiple different access technologies. In this context, we analyzed the issues of discovering the available

Access Priority	User Priority (UP)	Access Category (AC)	Designation
3	1, 2	AC_BK	Background
2	0, 3	AC_BE	Best Effort
1	4, 5	AC_VI	Video
0	6, 7	AC_VO	Voice

Table 3. User Priority to Access Category mapping [21]

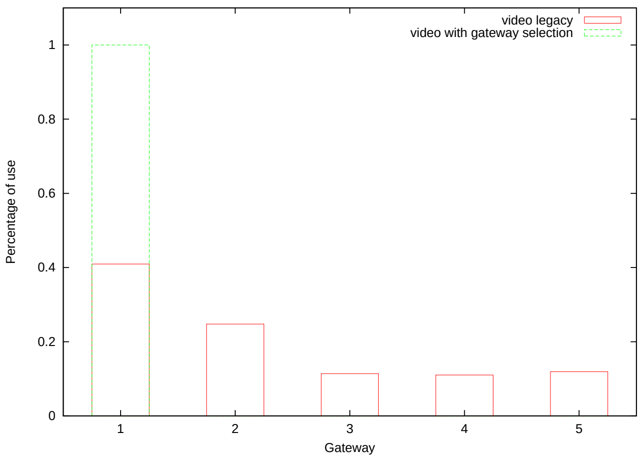

Figure 5. Percentage of packets serviced by each gateway for video flow

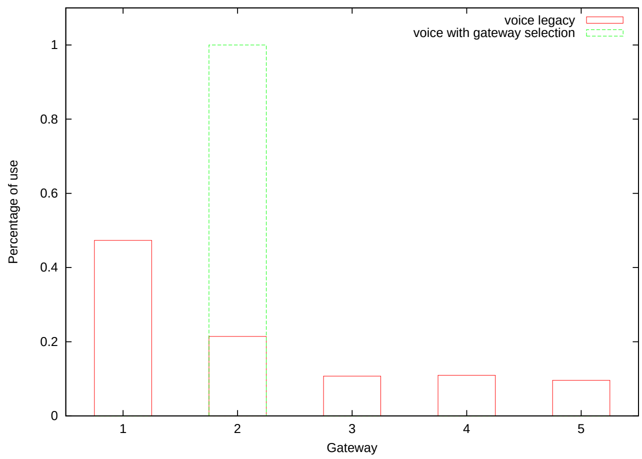

Figure 6. Percentage of packets serviced by each gateway for voice flow

gateways in the mobile hot spot area, and discovering the route towards them. This is a "multi-dimensional" problem which involves service requirements, network type and resources availability, and other high layer parameters, such as cost, hotspot and telecom providers. We proposed a combined approach based on functionalities of SDPng and AODV protocols, suitably extended to provide quality of service support and Internet gateway discovery. Following an extensive simulation campaign the proposed approach proved to outperform the legacy solution improving the service quality achieved by travelling users.

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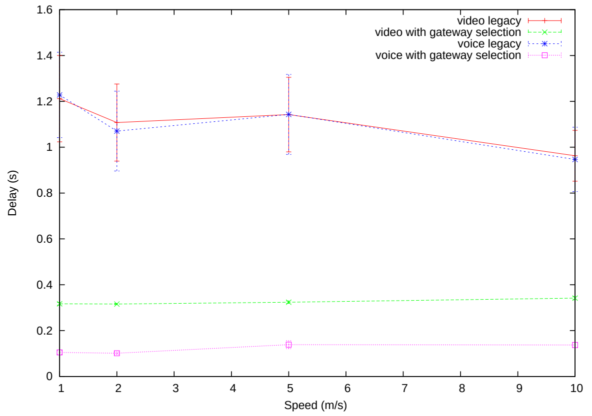

Figure 7. Delay experienced by voice and video flows under different mobility scenarios

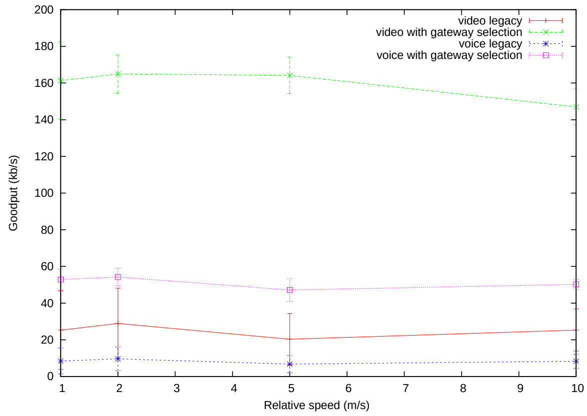

Figure 8. Goodput of voice and video flows under different mobility scenarios

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