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Mobility and Network Selection in Heterogeneous Wireless Networks: User Approach and Implementation

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Abstract

The Intelligent Transport Systems (ITS) wireless infrastructure needs to support various safety and non-safety services for both autonomous and non-autonomous vehicles. The existing wireless infrastructures can already be used for communicating with different mobile entities at various monetary costs. A packet scheduler, included in a shim layer between the network layer and the medium access (MAC) layer, which is able to schedule packets between uncoordinated Radio Access Technologies (RATs) without modification of the wireless standards, has been devised and its performance evaluated. In this paper, we focus on the influence of mobility type in heterogeneous wireless networks. Three cases are considered based on the mobility in the city: walking, cycling, and driving. Realistic simulations are performed by generating mobility traces of Oxford from Google Maps and overlaying the real locations of existing WiFi Access Points. Results demonstrate that the shim layer approach can accommodate different user profiles and can be a useful abstraction to support Intelligent Transport Systems where there is no coordination between different wireless operators.

Keywords: Heterogeneous Wireless Networks, Intelligent Transport Systems, Mobility, Scheduling Algorithm, Shim Layer, Vehicular Communication

1 Introduction

Various techniques are used to provide traffic information about hazardous situations to users in the current transport infrastructure: messages are broadcast via the Frequency Modulation (FM) radio temporarily interrupting the user-tuned reception or message signs are placed at strategic points (tunnels, bridges, highway connections, bus stops, city entrance). The current advancement made in wireless communications provides numerous possibilities for offering drivers different levels of service, ranging from safety messages (e.g. car breaking in front) to infotainment. In ITS and Smart Cities, dissemination of safety information will not only concern vehicular nodes but it can involve cyclists and pedestrians.

An integrated heterogeneous architecture with multiple wireless technologies can answer to the various and broad ITS requirements. These integrated architectures are expected not to require modifications at the lower layers so that different wireless technologies can operate independently. Thus, the key of future networks is to make the heterogeneity transparent to the upper layers and provide a transparent, and self-configurable service for maximum connectivity that can respond to all the ITS requirements. Other aspects to consider include transmission power selection for a given communication interface, co-channel interference, topology discovery, route creation, mobility, handoff management, and load balancing.

Directly applying the existing communication approaches designed for traditional mobile networks to large-scale vehicular ad-hoc networks (VANETs), and/or ITS, with fast-moving nodes can be ineffective and inefficient. For instance, cellular technologies are presently the only solution to upload data from vehicles to control centres, with a large impact on cellular resource usage [1]. Although cellular networks are capable of providing wide coverage for vehicular users, the stringent requirements of real time safety applications cannot always be guaranteed.

Most of the proposed mechanisms focus on the decision mechanism and do not provide information about how the additional functionality can be integrated into existing standards. To this end we proposed a novel shim layer approach [2] that sits between the MAC Layers of the different wireless technologies and a single IP layer (Section 3). The shim layer hosts an algorithm that can schedule packets based on different user profiles and can respond to different Quality of Service (QoS) requirements (Section 4). No architecture modification is required on the operator side and the technologies can be under the control of different operators. The communications observe a common characteristic of one-hop (single-hop or infrastructure) operation mode, wherein users access the system through a fixed base station (BS) or Access Point (AP) connected to a wired infrastructure. Such an approach is not only valid for heterogeneous vehicular networks but can also be adopted by mobile devices to access the Internet.

If using such a heterogeneous wireless approach where no coordination is needed between the APs, what is the influence of the mode of transport? Another key question is how can well established networks, such as WiFi and cellular, help with the mobility of nodes communicating in an urban environment? How much of the messages could be offloaded from the cellular link to the existing WiFi APs and thus reduce cost? In this paper, Google Maps mobility traces have been used to provide a high degree of realism and existing Access Point locations have been overlaid on the simulation map (Section 5). To observe the influences of mobility type on a heterogeneous wireless system in an urban environment three different transport methods (walking, cycling and driving) have been simulated in two scenarios.

The rest of this paper is organized as follows: in Section 2 the ITS communication challenges are requirements are discussed. Section 3 presents the node architecture and related work, followed by Section 4 which describes in detail the shim layer. Section 5 presents the simulation scenario and results. Finally, Section 6 concludes this paper.

2 Intelligent Transport Systems Background

Different aspects of ITS and some of the encountered challenges and requirements are discussed in this section. Message categorisation and ITS requirements are presented in section

2.1. An overview of cellular networks and their influence on vehicular networks is described in section 2.2, followed by the available transmission schemes in heterogeneous networks - section 2.3.

2.1 Messages in Intelligent Transport Systems

ITS services can be broadly categorized into safety and non-safety services [3]. The safety related services can be split in four categories, namely 1) vehicle status warning, 2) vehicle type warning, 3) traffic hazard warning and 4) dynamic vehicle warning. An example of user case for each of these categories is respectively: emergency electronic brake lights, motorcycle warning, roadwork warning and overtaking vehicle warning. The minimum frequency of periodic messages of the safety service varies from 1 Hz to 10 Hz, and the reaction time of most drivers ranges from 0.6 to 1.4 s [4]. It is thus reasonable to restrict the maximum latency time to be no more than 100ms [5].

The non-safety services are used primarily for traffic management, congestion control, improvement of traffic fluidity, infotainment. The main objective of non-safety services is to enable a more efficient and comfortable driving experience. They can be split roughly into two categories: traffic efficiency and infotainment services with applications such as intersection management and media download respectively. Compared to safety services, non-safety services have different QoS requirements. For most non-safety services, the minimum frequency of periodic messages is 1 Hz, while the maximum latency is 500ms [5]. A non-exhaustive table can be found in [5].

In all cases, high-level security is required for both safety and non-safety related services. For instance, in the latter case, monetary transactions such as electronic tolls have to be authoritative and endorsed by traffic management authorities.

2.2 Vehicular Networks and Cellular Influence

Since the infrastructure of cellular networks has been widely deployed for the past decades, it is economically efficient to utilize cellular networks to support Vehicle-to-Infrastructure (V2I) communications [6]. Hossain et al. [7] believe that an Advanced Heterogeneous Vehicular Network (AHVN) that uses multiple radios and multiple access technologies in a collaborative manner could be the best candidate for a vehicular network. Their key motivation is that the Dedicated Short Range Communications (DSRC) project will only be effective when it is ubiquitously deployed, but this will not happen until the needed infrastructure is in place, governments legislate for DSRC deployment in passenger vehicles, and older non-compliant vehicles have retired.

Lequerica et al. [8] have shown that cellular system-aided (3G/LTE) heterogeneous vehicular networks can greatly facilitate message dissemination in terms of message delivery ratio, outperforming pure vehicular ad-hoc networks with sparsely placed vehicles. Based on this research Ho Ting Chen et al. [9] state that one viable option to improve the network connectivity in VANETs for infotainment and road safety service support is via the assistance of a well-established cellular system as a complementary network. Nevertheless, V2I communications have a large impact on cellular resource usage [1].

LTE is envisioned to support V2I communications especially in the initial deployment stage of vehicular networks and play an important role in rural areas where the vehicle density is low. LTE can provide uplink data rates up to 50 Mbps and downlink data rates up to 100 Mbps with a bandwidth of 20 MHz, and supports a maximum mobile speed of 350 km/h. It can service up to 1200 vehicles per cell in rural environments with an uplink delay under 55ms [3]. On the contrary, the WCDMA (3G) system cannot support well the safety services in vehicular communications: the delivery latency is in all the states larger than the allowed maximum latency for safety services (100ms). Also, the connection setup from an idle state in WCDMA requires 2-2.5 s. In addition, in highly dense areas, such as cities, with numerous building reflections, the performance of cellular connectivity can vary based on the number of users. Devising effective and efficient resource management approaches tailored for integrated VANET/3G-LTE networks is a complex task and needs further investigation.

One of the complementary networks to support an integrated approach can be the existing WiFi technology with Access Points largely spread around the city. WiFi can provide an alternative for non-safety messages and safety messages in the third category (traffic hazard warning). This can release the cellular network from extra pressure and reduce cost in the initial stage.

2.3 Transmission Schemes in Heterogeneous Networks

A multi RAT terminal features interfaces for multiple technologies. The packets are sent to the same receiving host, although they follow different network access paths, through different Base Stations/Access Points. Three transmission schemes are possible for heterogeneous wireless communications (parallel with redundancy, parallel without redundancy and switched) [2]. It is to be noted that frequent switching can lead to performance degradation [10]. Performance may be enhanced by limiting path switching to channel variations large enough to ensure considerable performance gain instead of switching even for small changes that may not yield any significant gains. Also, activating multiple network interfaces on a multimode terminal may significantly increase battery power consumption, thereby shortening the terminal's battery lifetime and risking premature transmission termination.

Although heterogeneous networks bring advantages, a number of issues arise. In addition to the duplicate acknowledgements issue [11], delays related to packet re-ordering at the receiving end are common. In Earliest Deadline Path First (EDPF) [12] the scheduling algorithm artificially throttles transfer rates on faster paths with the aim of receiving packets in order and thus reducing the time needed to re-arrange them. This is not an acceptable solution for safety-critical information as it can cause an increase in delay but also a drop in link utilization and throughput. To solve such priority issues, a QoS approach has been taken by the 802.11e amendment with a traffic type classification mechanism but it is only applicable for wireless LAN applications (802.11) and does not include other RATs, such as cellular or Bluetooth.

3 Node architecture and Related Work

The description of the node architecture influences the related work that is to be presented. Thus, in this section the node architecture is presented in section 3.1, followed by the related work in section 3.2.

3.1 Node Architecture

Selection of a non-optimal network may lead to undesirable results such as poor QoS or the use of a more expensive network [13]. When an operator controls all the APs and BSs, such as in [14], they are able to choose the optimal solution for a given user. However, when a user has visibility of multiple APs that are not under the control of the same operator, the optimal selection of access technology should be at the user-end.

To this end and to maximise the use of existing standards, our system maintains the Media Access Control (MAC) and Physical (PHY) layers unmodified. A shim layer, referred to as a layer '2.5', is proposed which is inserted between the network layer and the MAC layer of each of the wireless access technologies. Fig. 1 depicts the system model. This shim layer hosts the Multiple Interface Scheduling System (MISS) modules that are described in section 4. The algorithm (section 4.2 - Fig. 4) sends packets to the selected RATs, making the selection transparent for the upper layers. Each RAT exhibits different physical and logical features. They may use different frequencies or modulation schemes at the PHY layer, and they may use different media access techniques at the MAC layer. An important feature of this scheme is that one single Network/IP layer can characterise each node. Such an approach can be implemented for any IP based wireless technology/network and is not only restricted to vehicular networks.

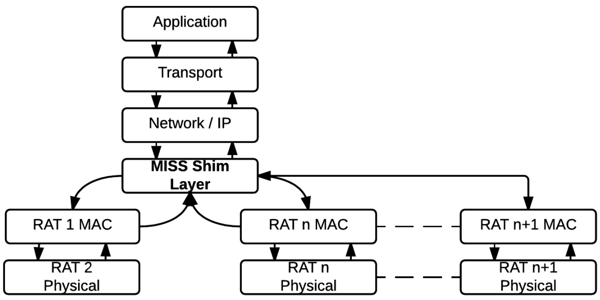

Figure 1: Conceptual Model of the Shim Layer

3.2 Related Work

In previously reported work, scheduling without modification of the wireless standards, has been carried out at the application layer [15], transport layer [11] and network layer [10] of the Open Systems Interconnection (OSI) layered data model. A full review of the different advantages and disadvantages of scheduling at these different layers can be found in [16].

The advantage of implementing the data scheduling at an intermediate level between the MAC layer and the IP layer is that the solution is tailored to the available lower layers and transparent to all the upper layers. There is no modification to the existing wireless standards (PHY and MAC layers) and one device can have one IP address, in contrast to previous mentioned solutions which require one IP address for each RAT. A similar intermediate shim layer approach between the network layer and the MAC layer was proposed by IEEE 802.21 Media Independent Handoff (MIH) but the key feature was to provide a common interface for managing events and control messages exchanged between network devices [17].

There is an important difference between the uplink and downlink in our shim layer approach. The focus is set on the uplink, rather than the downlink, as several emerging applications treat vehicles as data sources in mobile sensor networks, where a variety of sensors (GPS, cameras, on-board diagnostics) acquire and deliver data about the surrounding environment [18]. The uplink model does not require any changes to the current infrastructure as the packets will be forwarded to the Base Station/Access Point and from then on the packets follow

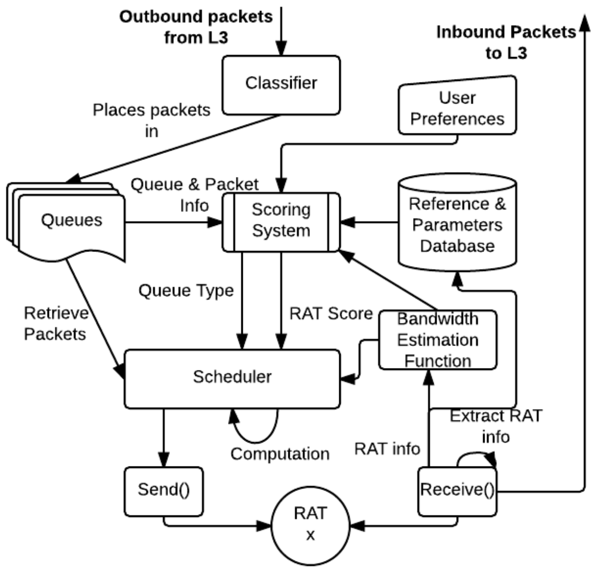

Figure 2: Shim Layer Flowchart

a standard route to the destination. The problem of packet reordering at the receiver is handled by the upper layers. A single path is used for downlink.

4 Shim Layer Contents

In this section the modules of the shim layer and their connections are explained. The links between the shim layer components can be observed in Fig. 2. The three most important modules are the 'Scheduler', the 'Scoring System' and the 'Bandwidth Estimation Function'.

The 'Scheduler' is split in two sections and is described in detail in section 4.2 for the MISS algorithm and section 4.3 for the process related to the parallel transmission decisions. The full details of the scoring system, based on six parameters: bandwidth, delay, SINR, node velocity, energy consumption and cost are beyond the scope of this paper and can be found in our previous work [19]. The 'Bandwidth Estimation Function', based on work from [20], is used only when a non packet by packet approach is taken. The 'User Preference' module is described in detail in Section. 4.1 and discusses the influence user profiles have on the 'Scheduler'.

The 'Classifier' receives packets from the upper layer (IP Layer) and distinguishes between five different packet types: Video, Voice, Background, Best-Effort and Safety. It then places the received packets in different 'Queues' that will be accessed by the 'Scoring System' and the 'Scheduler'. The 'Scheduler' is asynchronous to the classification of the packets in the different queues.

When a packet is received by the underlying MAC Layer, the extracted info is used by the 'Bandwidth Estimation Function' and the 'Reference & Parameters Database'. The 'Reference & Parameters Database' holds the reference values that define the minimum delay and bandwidth necessary for each application/queue type. Further details can be found in our previous work [2].

4.1 User Profiles

To cope with growing heterogeneity in data access, it is critical to identify and optimize strategies that can cater to users of various profiles to maximize system performance and more importantly, improve users quality experience [21]. One of the challenges is to produce a scheduling algorithm that is able to react correctly if two communicating devices have different profiles. For example one user with a parallel transmission profile communicates with a user that uses a cost effective profile. Karthikeyan Sundaresan et al. [21] present an initial design of an algorithm TRINITY which caters to a heterogeneous set of users spanning multiple profiles simultaneously built onto the reference structure - without modifying the current structure of the existing wireless technologies.

A non exhaustive list of some of the user profiles that can be used in the shim layer can be found in Fig. 3. If the profiles are combined they can become even more complex, for instance providing access with a High Priority and Cost Effective profiles. The most stringent requirement will take over and thus only a Single RAT may be used, unless safety messages are involved - further described in section 4.3.

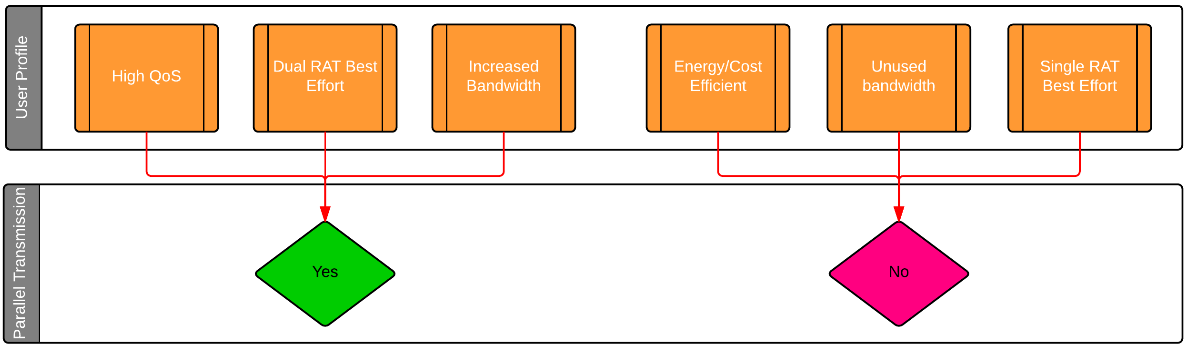

Figure 3: Examples of User Profiles

The user profile choice outputs values for the scoring system, in terms of allocated weights to the Cost and Energy Consumption scoring attributes. It also influences the parallel transmission decision by indicating if multiple RATs can be used by the node.

4.2 Scheduler - Algorithm

The scheduler's main purpose is to distribute the packets from different queues based on user choice by responding to QoS requirements and safety critical applications. Any QoS routing algorithm has to strike a balance between overhead and quality. Multi Attribute Decision Making (MADM) algorithms have been used in heterogeneous wireless network environments, in order to choose the best RAT, to find acceptable alternatives or to find the best alternative [22]. A direct comparison between these algorithms is difficult as it requires the use of another MADM algorithm. They can nevertheless be split into two main categories: compensatory and non-compensatory.

Compensatory algorithms combine multiple attributes to find the best alternative, such as Simple Additive Weighting (SAW), Multiplicative Exponential Weighting (MEW), Gray Relational Analysis (GRA), Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). GRA uses a reference matrix, set subjectively by the user, to compare the matrices obtained for each network. An advantage of the GRA approach compared to the other listed

Figure 4: MISS Scheduler Algorithm

q : queue
z : chosen queue to send packets from
n : number of packets to send
m_z : max packets (%) to send (percent of n)
a : number of available RAT
S_{xz} : Score of RAT x for queue type z
loop (void)
  calculateSchedulerAvailableRATs()
  queue()
  trafficDistribution(z,n)
  If $a \neq 0, \forall q \neq z$, queue();
end loop
function $queue$(void)
  Check length of each Queue (q)
  if $q_{safety} \neq 0$ **then** $z = q_{safety}, n \leq m_{safety}$
  else if $q_{video} \neq 0$ **then**
    $z = q_{video}; n \leq m_{video}$
  else
    $z = q_x; n = m_x;$
  end if
  return z, n
end function
function $trafficDistribution$(z, n)
  getRATScores(n)
  $n \rightarrow \forall$ RATs, $S_{xz} > 0$
end function
function $getRATScores$(queueType)
  Calculate S_{xz} **return** S_{xz}
end function
function $bandwidthEstimationFunction$(RAT)
  Calculate m_z **return** m_z
end function

* $\rightarrow$:to be read as *'send on'*

algorithms is that it selects the network that offers a QoS closest to that which is being requested by the service, and not the network that has the best QoS but exceeds by far the services' QoS requirement. On the contrary, non compensatory algorithms are used to find acceptable alternatives which satisfy a minimum cut-off [23].

Our algorithm approach is a combination between the two: we adapt a compensatory algorithm by adding minimum cut-off values and calculating the resulting score. To base its decision, the scheduler, takes as input the score for each RAT provided by the 'Scoring System' [19] and the 'Bandwidth Estimation Function'. The scheduling algorithm presented in Fig. 4 has the following procedure:

1. Determine the number of available RATs for each iteration.
2. Determine the queue type to send packets from (z) and the number of packets to send (n).
3. Calculate the score (S_x) of each available RAT for the retrieved queue (z).
4. Packets are sent on the available RATs with $S_x > 0$.
5. If there are available RATs remaining for that iteration, the process is repeated for the lower priority queues (only for Parallel Transmission Profiles).

4.3 Scheduler - Parallel Transmission

The parallel transmission mechanism flowchart (Fig. 5) is part of the 'Scheduler' and is RAT independent. This process is performed for each iteration of the algorithm. As described in the previous section, the user profile selection influences the scoring of each RAT and the possibility of using multiple RATs. We assume that the safety packets should still be retransmitted if the receiver has a benefit of interpreting the late messages. For instance, an 'Ice Warning' can be beneficial but an 'emergency electronic brake lights' might not. The packets are tagged with the 'Late Tag' and replaced in the safety queue for retransmission even if their chances of arrival to the destination are low. These replaced packets in the safety queue will be discarded by the shim layer queue if the delay value exceeds the threshold or if the packets expire. The 'RAT change' scenario is only active if a non parallel transmission profile is chosen.

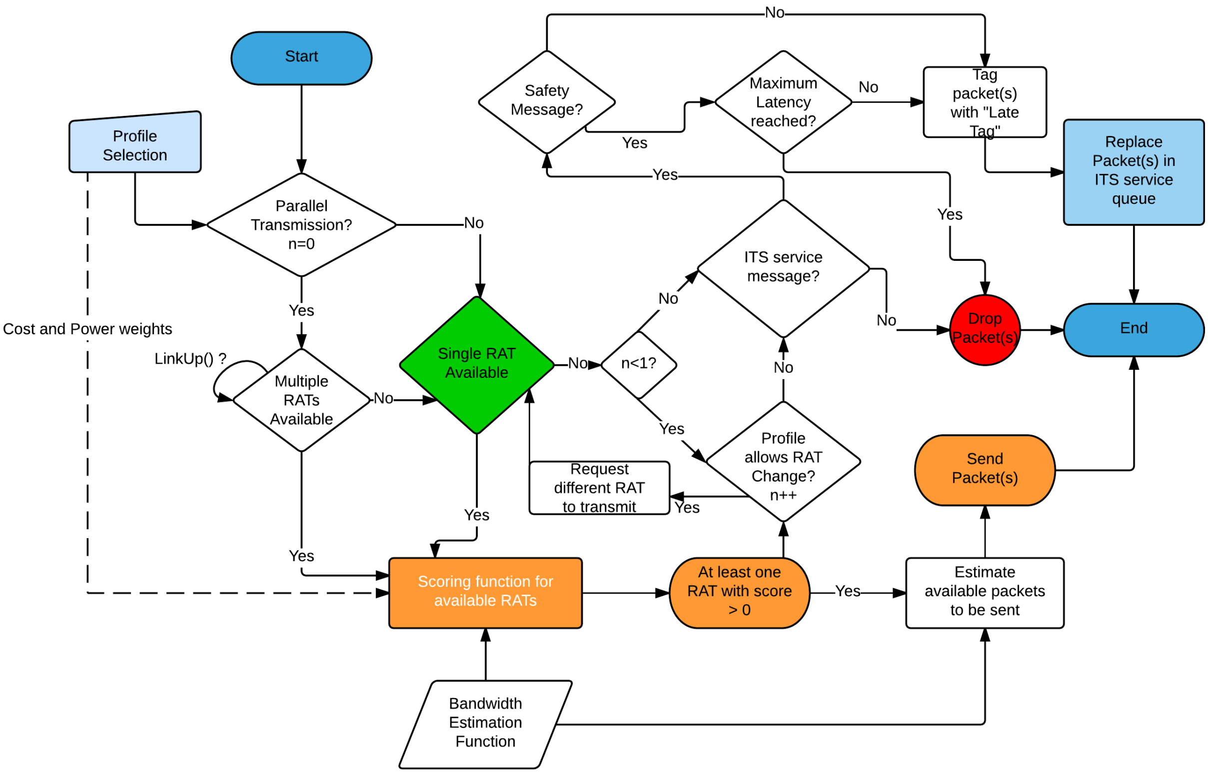

Figure 5: Parallel Transmission Flowchart

5 Simulation

The simulation objective, performed with Network Simulator 3 [24], is to show what mobility type is the most cost efficient way, from a wireless communication perspective, of travelling within a dense urban environment. If we assume WiFi is the most cost-effective RAT, how much of the data can be offloaded from cellular to WiFi? Another objective is to show that the shim layer can respond to different profiles in ITS.

The full performance evaluation of the shim layer and algorithm, under ideal conditions or saturation, has been evaluated in previous papers and the results can be found in [2] [19] [25]. In [2] we introduced the shim layer concept and proved its functioning. In [25] we demonstrated that the shim layer can improve video delivery quality by prioritizing the most important frames. It is to be noted that this study is an extension to our previous work [19], where we demonstrated that the shim layer can prioritize safety messages regardless of the level of saturation of the link.

5.1 Simulation Environment

Three different transport methods are compared: driving, cycling and walking. The simulated city center part can be observed in Fig. 6. The full interactive map is available to view online [26]. Two scenarios are tested:

1. The nodes are travelling between Oxford Train Station (A) and Oxford Brookes University Headington Campus (D). This scenario involves different routes for the 'walking' and 'cycling'/'driving' nodes due to the traffic restrictions in Oxford City Center.
2. 'High Street Scenario': The nodes are travelling from 141 High Street (B) to Cowley Place (C). This area is characterized by a high number of available APs. All nodes follow the same route.

Table 1: NS-3 Simulation Parameters

Parameter	Value
Wi-Fi Transmission Rate Transmission Range	802.11n 2.4GHz 5.5Mbps 25m
Shim Layer Queue Type	CoDel
Propagation	Two-Ray
Data Traffic Packet Size	128kbps 1448 Bytes
Transport Layer Network Layer Addressing	UDP IPv6 Static
Node Speed	Various
Simulation time Walking Cycling Driving	Various 3121s 1181s 849s
Network Simulator	NS-3.22

Table 2: WiGLE Results

Parameter	Value
Latitude 1 Longitude 1 Latitude 2 Longitude 2	51.738 -1.3066 51.7651 -1.1941
Date Range	01/01/2015 - 06/04/2016
SSID	eduroam
Total APs QoS $>$ 0 QoS $>$ 1 QoS $>$ 2 QoS $>$ 3 QoS $>$ 4 QoS $>$ 5 QoS $>$ 6	1606 985 934 545 498 288 236 162

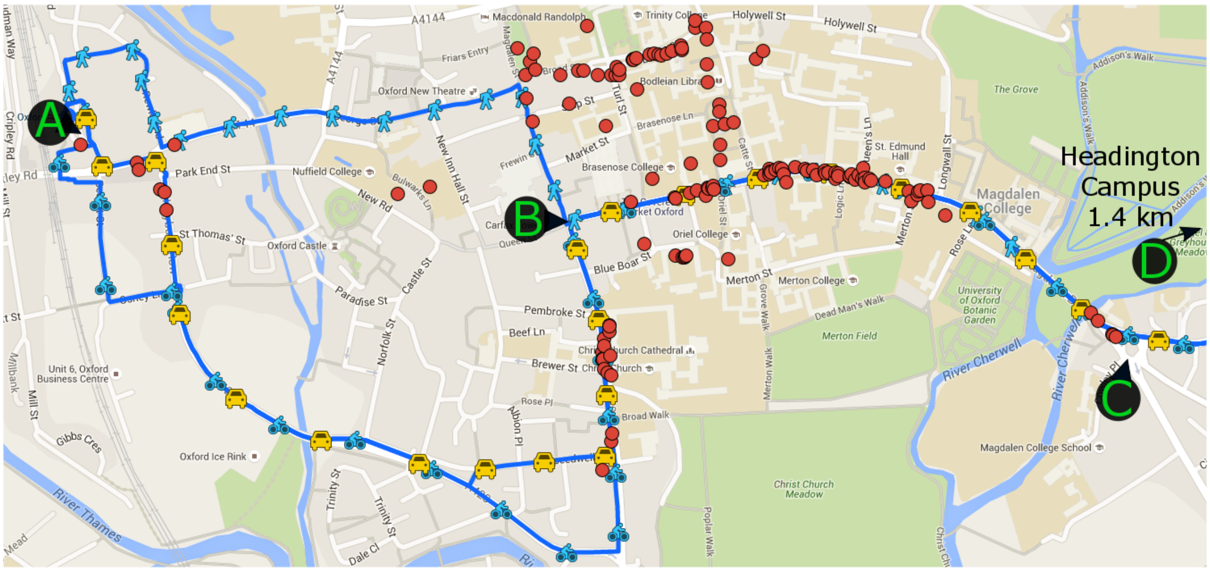

Figure 6: Google Maps Mobility Caption of Oxford City Center overlaid with Eduroam AP locations

It is assumed no authentication is required and a static IP address scheme is used. This is necessary to allow the shim layer to have only a single IP address. We also assumed a full cellular link coverage and that all packets that could not be sent over WiFi are sent over cellular.

The full simulation parameters can be observed in Table 1. One specificity of CoDel [27] is that rather than measuring queue size in bytes or packets, CoDel uses the packet-sojourn time through the queue. The CoDel queue eliminates the expired saturation packets from the queue, thus reducing the queue time. The available AP bandwidth for a single user is limited to 5.5 Mbps, even though the maximum available throughput for one AP is 27.1 Mbps, to avoid a single user using all the available bandwidth. We assumed such a rule is implemented in the real APs. The node sends a constant data traffic of 128kbps over the entire simulation.

5.2 Real World Data

The Routes Mobility Model package [28] was used to integrate the Google Maps mobility and directions in NS-3. The nodes try and maintain real-world speed for the type of road they are travelling: decelerating for a curve, a roundabout, an intersection, etc, and accelerating after those obstacles are overcome.

The Eduroam (education roaming) APs were chosen to be used as potential usage for ITS as they are omnipresent in the center of Oxford due to the numerous University of Oxford buildings. Eduroam is the secure, world-wide roaming access service developed for the international research and education community. It allows students, researchers and staff from participating institutions to obtain Internet connectivity across campus and when visiting other participating institutions [29].

The Eduroam APs locations were extracted from the WiGLE [30] database. WiGLE is a crowd-source website for collecting information about WiFi APs. The selected area is between GPS coordinates 51.738, -1.3066 and 51.7651, -1.1941, which corresponds roughly to the area of Oxford inside the ring road. The results can be seen in Table 2. The QoS parameter is an

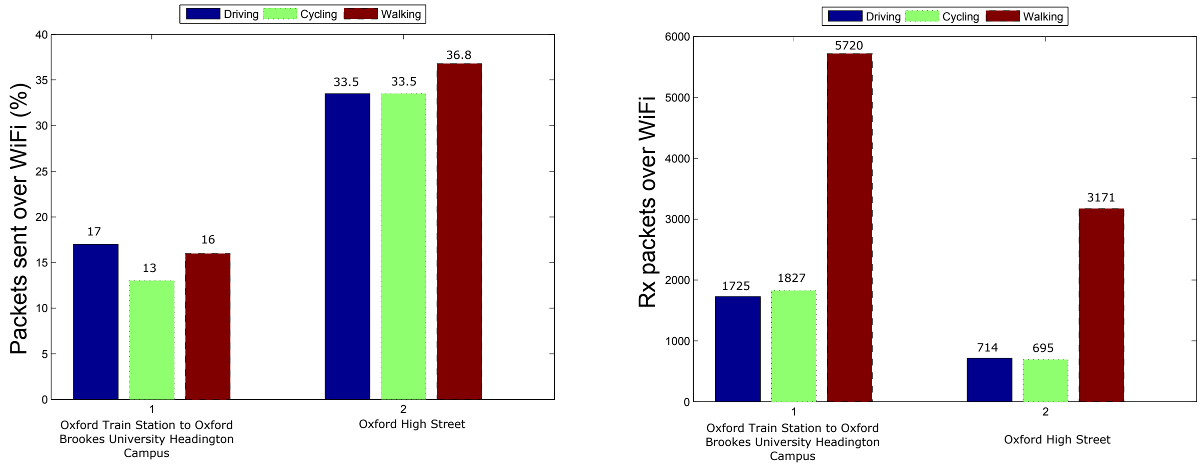

Figure 7: Percentage of data and number of sent packets over WiFi

arbitrary WiGLE metric for an observed point: if an AP is seen on more than one day, or by more than one user, the value increases as it is more likely to be stable. If the AP is seen only once by one user, the QoS is set to 0. The QoS value increases with the number of views by different users and the maximum value is 7. In the represented table, we indicate how many APs were found with a QoS larger than a specific value. For example, there are 1606 APs with a QoS of 0 or higher, and 985 with a QoS strictly superior to 0. This includes all the APs with a QoS equal to 2, 3, 4, etc. For the simulation we have chosen only the APs with the highest QoS, strictly superior to 6, resulting in 162 APs. From the total number of APs (1606), twelve are 5 GHz APs. These APs have been considered as 2.4GHz for the purpose of the simulation. The transmission range of each AP is set to an arbitrary value of 25 meters. The range of the AP has been limited in order to take into account the attenuation from the buildings. It is difficult to simulate such parameters as the signal strength of an AP and its range can vary based on its surrounding environment.

5.3 Results

In Fig. 7 the percentage of data and number of packets sent over WiFi for the different mobility types is presented. It is to be noted that in the first scenario, driving has a higher percentage than cycling and walking due to the speed of the node, but also the route - the nodes respect traffic rules and take the shortest path for their mobility type. The route is also the reason why the walking node does not have a higher percentage of data sent over WiFi in the first scenario. In the ’High Street Scenario’, where all nodes follow the same route, the walking node has a higher percentage than both cycling and driving: 36.8% vs 33.5%. It can also be observed that a walking node is capable of sending 3 times more data over WiFi, 5870 packets against 1827 packets, than the other means of transport in the first scenario, and 4 times in the second scenario - 3171 packets against 714 packets (Fig.7). This is related to the time each node spends in the area of an AP.

To further evaluate the functioning of the shim layer, the delay values of two different profiles were compared in the ’High Street Scenario’ (Fig. 8). The ’High Quality of Service Profile’ uses parallel transmission and uses both links to transmit a packet. The ’Single RAT Cost Efficient Profile’ uses only WiFi, when available, to transmit the packets. It can be ob-

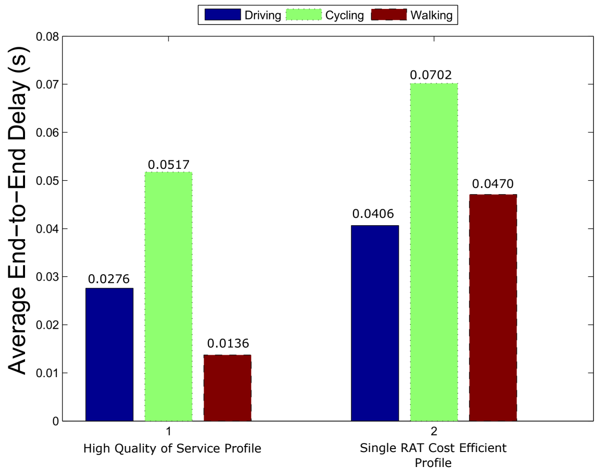

Figure 8: Comparison of End-to-End Delay for WiFi only profile vs High QoS profile

served that the 'High Quality of Service Profile' has an average end-to-end delay 0.02s lower than a 'Single RAT Cost Efficient Profile'. The highest end-to-end delay is observed for the 'cycling node'. This can be explained by the constant speed of the 'cycling node' and the resulting handovers. Even if the vehicle 'driving node' speed average is higher than the cycling, the variations are larger. The car node speed is influenced by intersections, traffic lights and curves while the bicycle node has a more constant speed, even if is slower.

6 Conclusion

In this paper, we further evaluated our network selection uplink scheduling algorithm in relation to various mobility types. Realistic simulations were performed by generating realistic mobility traces of Oxford and overlaying the real locations of existing WiFi Access Points. With the existing infrastructure, a 'walking node' in Oxford City Center is capable of sending 4 times more data over WiFi than the other means of transport over the same route. Also, a 'driving' node has a higher delivery percentage over WiFi than a 'cycling node' due to the variations of speed. The algorithm accommodates different performance metrics and can adapt its decisions based on user-specified profiles. Two profiles have been tested and it was shown that the end-to-end delay can be reduced if a parallel transmission profile is chosen. The shim layer can be beneficial for a heterogeneous wireless network in Intelligent Transport Systems.

Future work includes performance evaluation with multiple users and a comparison between simulation results and hardware implementation. Another aspect to study is the difference between a coordinated and uncoordinated multi-node algorithm approach.

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