Service-based network selection in C-ITS vehicular networks

Lincoln Herbert Teixeira* and Árpád Huszák

Department of Networked Systems and Services,
Faculty of Electrical Engineering and Informatics,
Budapest University of Technology and Economics,
Budapest, Hungary
Email: lincoln@hit.bme.hu
Email: huszak@hit.bme.hu
*Corresponding author

Abstract: Cooperative intelligent transport systems (C-ITS) are made up of vehicular applications and provide a framework for road users and traffic managers to share information between stakeholders. Different access technologies exist that can support V2X communication, however, each one has its own advantage and drawback and cannot be used effectively for all types of services. The alternative to avoid this issue is to employ multiple networks and select the best one available, by using an intelligent network selection algorithm. It is also possible to use extra information, like position and navigation route information, to predict the distances between the hosts to improve the user experience. This work presents the SISS algorithm and compares its performance with the widely used TOPSIS algorithm to decide which network option is the best for each application, taking the service requirements into account.

Keywords: cooperative intelligent transport systems; C-ITS; interface selection; navigation route position; network communication; service-based interface selection scheme; SISS; TOPSIS.

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Biographical notes: Lincoln Herbert Teixeira received his MSc in 2009 as an Electrical Engineering and Industrial Informatics from the Federal University of Technology – Parana, Brazil. He is currently a PhD student of Computer Engineering at Budapest University of Technology and Economics (BME), Hungary.

Árpád Huszák received his MSc in 2003 as an Electrical Engineer from the Budapest University of Technology and Economics (BUTE) at the Department of Telecommunications (currently Department of Networked Systems and Services). He received his PhD in Electrical and Computer Engineering in 2010. He is currently with the Department of Networked Systems and Services as an Assistant Professor, but he also joined the Mobile Innovation Center Hungary (MIK). He is member of the IEEE and

HTE. Recently, he has been involved in many European projects (FP6-IST, FP7-ICT, and Celtic). His research interests focus on network protocols, mobile computing and adaptive multimedia communication over wireless networks.

1 Introduction

Applications based on vehicle-to-everything (V2X) communication is an emerging and promising area within the cooperative intelligent transport systems (C-ITS) environment that will support road users and traffic controllers to use the information hastily to decrease the number of vehicle hazards, improve the traffic management, optimising travel time and fuel consumption (Cui and Yan, 2017). The V2X communication, includes vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), vehicle-to-network (V2N) and vehicle-to-pedestrian (V2P) connections as defined by 3GPP (2017).

For the success of real-time V2X communications, it is essential that networks be reliable, resilient, and secure in the transmission of information. Dedicated short range communications (DSRC) and conventional cellular networks (C-V2X) are promising technologies to facilitate vehicular communications (Ndashimye et al., 2017). These radio access technologies (RATs) standalone cannot support the communication requirements of advanced applications. It would be crucial to implement autonomous vehicle's systems (Naik et al., 2019). The increasing data traffic on vehicular networks will probably overwhelm the capacity of channel systems of these wireless networks in a long-term (Higuchi and Altintas, 2018; Abdelatif et al., 2020).

The main goal of the future networking is to use heterogeneous RATs simultaneously (Chahal and Harit, 2019; Zhou et al., 2018; Chakrabarti and Das, 2019; Krishnareddy and Rangaswamy, 2018), it means, to keep more than one radio device active, and dynamically select the proper interface to transfer their data conforming the vehicle's situation (e.g., signal power, channel capacity, road situation, distance between the vehicles and application requirements) to improve the communication performance. The different features of the wireless transmissions, followed by an intelligent decision system to select the network, complement each type of radio and at the same time improve resilience and accuracy of wireless communications systems (Higuchi and Altintas, 2018). It is known that cellular systems offer the advantage of handover technique, and there are previous studies to optimise them for vehicular networks (Shafiee et al., 2011; Shukla et al., 2017; Gukhool and Cherkaoui, 2010). Meanwhile, the difficulty of mobility in the network layer remains unsolved (Wu et al., 2011). Natively, the IP protocol does not provide mobility and the academic society and industry are making an effort to improve the mobility headers in IPv6 (Oh et al., 2009), so the implementation and acceptance of this feature will necessarily take time. Also, a promising paradigm of future internet architecture, content-centric networking (CCN), especially in V2V network is arising. Wang et al. (2016) shows that the naming scheme forwarding mechanism can be a promising solution for the vehicular information network in the future internet.

This work deals with this demand, it intends to design a changeover process, while the implementation of IPv6 mobility is not ready for a vehicular network (Santa et al., 2017). Also, it is necessary in the V2X environment to ensure that the network systems will satisfy the requirements of the vehicular applications to be able to guarantee the quality of service/experience (QoS/QoE). Currently issues of QoS in vehicular ad hoc network are shown by Karthikeyini and Shankar (2019). Using extra information available in the sensors of the vehicles, as suggested in the management cross layer in the C-ITS architecture (ETSI, 2012) it is possible to make any decision even more intelligent. This paper addresses the use of information from the Global Navigation Satellite System (GNSS), available in any car navigation application, to calculate the distance between vehicles during a certain time. With this extra information we expect to select the best network available in the C-ITS system that will provide the best user experience minimising the packet drops and improving the throughput, without just relying on the telecommunication service provider (TSP). This mechanism enables an efficient data offloading process under heterogeneous application's requirements.

Main contributions of this paper are summarised as follows:

- We propose a novel network selection and data offloading approach to satisfy the diverse requirements of C-ITS applications.
- We introduce the TOPSIS-based model for network selection using heterogeneous network interfaces.
- Thereafter, we propose the service-based interface selection scheme named as SISS, addressing the use of the GNSS information.

The rest of this research paper is organised in the following way: Section 2 reviews the related research work on network selection in heterogeneous wireless networks. Network selection scheme, problem formulation, and the mathematical approach are described in Section 3. In Section 4, we explain the simulation environment and, evaluate the simulation results. Finally, Section 5 concludes the paper with discussions.

2 Related work

With the fast development of wireless systems, the next generation network direction is to integrate heterogeneous networks for V2X communication. Two specific types of networks for C-ITS functions exist nowadays. The conventional cellular networks, for example: third generation, known as 3G-UMTS (universal mobile telecommunications system), fourth generation 4G-LTE (long-term evolution) and the next, the fifth generation 5G-NR (new radio), along with the DSRC IEEE 802.11p technology and it successor DSRC 802.11bd, are designed to meet the C-ITS applications (Wang et al., 2008) requirements. Although, the next generation of mobile V2X solutions, as 5G-NR and DSRC 802.11bd technologies bring many innovations in data communication (Katsaros and Dianati, 2017), it should not be ignored that these systems can be overloaded, because they will share access with other mobile devices. It is also necessary to remark that redundancy, cost of implementation and upgrading of systems still in the planning phase of future infrastructure deployment. Even though different network technologies may overlap, they will hardly substitute each other regarding their differences in coverage, system throughput, QoS, and mobility support (Zhang and Zhu, 2014). Muhammad et al. (2018) propose an orchestration framework for resource management and provisioning over clouds and networks, to meet such application's requests.

Service performance in a heterogeneous mobile network domain demands the selection of an ideal access network to offloading data (Zhou et al., 2018). The selection of an inappropriate network can cause disagreeable results such as disconnections and high delay. Different factors influence the selection of an optimal network in this situation, while a complete solution to solve that kind of problem is not yet available (Bari and Leung, 2007a), as most researches are focusing on single access network selection algorithms. To support uninterrupted mobility and meet the QoS required in some critical applications in heterogeneous wireless networks, we propose a network selection algorithm, where each host can communicate simultaneously with one or more network access. We believe that these two main network approaches, C-V2X and DSRC, will not be mutually exclusive but complementary to each other, and the two working together can improve the throughput and reliability of the communication system. For example, supposing that one vehicle has a connection in progress, and the same vehicle needs to transmit different information, but the requirements of this new solicitation does not fit with the network already in use. In such a scenario, the system can select other network interface available to transmit the new connection solicitation. This way it is possible to avoid unnecessary handover and implement an efficient offload mechanism. So, this approach is necessary because it is expected that vehicles should select and use the best network alternative to send their data.

Another area explored today in vehicular networks is channel congestion control. Several optimisation techniques have been applied in the past to solve congestion problems (Hamida et al., 2017). One such technique in Qureshi et al. (2018) is dynamic congestion control scheme (DCCS) has been researched for congestion detection and controlling strategies. They presented a scheme that detects congestion and controls it by exploiting existing network resources for road traffic safety communication. We have identified this work as complementary to our research to optimise network access increasingly.

Next, the relevant topics related to this work will be defined.

2.1 C-ITS network

With the emergence of new wireless technologies, it is necessary to identify parameters such as delivery range, mobility, reliability, scalability and delay for different scenarios, as was done in the Hameed Mir and Filali (2014) work. The authors described the effectiveness and flaws of each technology and investigated which technology is suitable for which use case. They considered two standards, the DSRC IEEE 802.11p, that provides adequate performance for sparsely mobile networks, and the 4G-LTE cellular, that meets mobility and scalability requirements. However, it is still a challenge to reduce the delay when it has large traffic loads.

A fundamental process is to identify how distinct wireless networks can meet current and future application specifications by supporting multiple radios for vehicles to use. Studies by Chen et al. (2017) show cases in V2V services in 3GPP and the standardisation of cellular LTE to fulfil the V2X requirements. Also, they discuss the challenges and detailed aspects of cellular network design for future 5G-NR solutions.

As with all technological modernisation, it is expected to have a smooth transition in network communication. By installing the new 5G-NR and DSRC IEEE 802.11p networks for C-ITS vehicle, existing legacy systems like 4G-LTE and 3G-UMTS will still be available for the users.

Katsaros and Dianati (2017) investigate current vehicle network architectures and their progression to 5G-NR. The main point of vehicular networking systems is to increase security with various other applications using this system to improve traffic performance and infotainment (Vijayan and Jeyanthi, 2017; Limbasiya and Das, 2018; Arif and Wang, 2020; Ahmed et al., 2019). They claim that the current architecture and performance of systems needs to be enhanced to meet C-ITS latency requirements.

To produce this work, we adopted 5G-NR, 4G-LTE, 3G-UMTS and DSRC 802.11p networks technologies, because these radio systems are the enablers of the C-ITS in a short and mid-term from their implementation. We developed use cases with distinct parameters, such as the bandwidth, delay, latency, distance limit range, and the costs of each access network to demonstrate the effectiveness of the network selection algorithms. The network parameters can be adjusted for future development of new radio technologies. In addition, this function is recommended for a smooth transition between technologies and for redundancy reasons.

The length of the connected link and its lifespan between network hosts are crucial issues that determine network performance and are critical to perform efficient communication that supports different application requirements in V2X environments. High node mobility in vehicles and density variations of hosts can cause frequent disconnections, leading to throughput performance issues (Abboud and Zhuang, 2015).

This poses new challenges in maintaining the connections between vehicle nodes. To optimise and maximise the length of the connected nodes, in this paper we will introduce a cross-layer information, the position and the navigation route of the vehicle, already available in any GNSS application.

2.2 *Vehicle position and route*

Using the information available in GNSS applications is required to measure the expected distances between the two hosts in the V2X communication environment. The performance gain can be analysed when we have the information route that the vehicle intends to follow. In the simulation section, we will explain how this information is planned to be used.

Route selection algorithms that uses Cartesian position and source information, have been developed by various researchers (Karagiannis et al., 2011; Pandey et al., 2016; Wang et al., 2016; Lee et al., 2020). The trajectory-based forwarding (TBF) algorithm combines source and position routing for ad hoc networks by selecting the path to the destination. They base TBF reference decisions on the path relationship and select the vehicle with the shortest expected data delivery delay as the next relay node. For a city vehicular traffic scenario direction-based location aided routing (D-LAR) protocol can be used and Pandey et al. (2016) propose an improvement using distance information, called distance and direction-based location aided routing (DD-LAR) protocol (Lee et al., 2020).

Safety applications are the most important motivating applications for V2X and have a particular behaviour. It should provide information to all surrounding vehicles, in other words, it demands a broadcast forwarding protocol to transmit the emergency signals. Broadcasting techniques such as flooding often suffer seriously from the storm problem and consume a large amount of bandwidth with many retransmissions and there can also be a session-expiration problem (Verma and Singh, 2017; Chitra and Siva Sathya, 2017). A different approach can be found in Meraihi et al. (2019) on how to solve the QoS for multicast routing problem. If the node density is high, this leads to many collisions and channel containment overload. Most research on broadcast routing algorithms proposes different solutions to this dilemma (Das and Misra, 2018; Xhafa et al., 2017). Including machine learning and heuristic techniques for wireless networks (Simi and Ramesh, 2019; El Fallahi et al., 2020; Nabovati et al., 2020). And for cellular networks, an emerging technology is the use of network slicing that will be implemented in future 5G-NR networks (3GPP, 2019).

3 Network selection scheme

Traditional cellular systems provide users mobility, however, when new technologies are implemented, e.g., 5G-NR, the costs to users and the possibility of congestion are high due to the new infrastructure not being fully implemented and the growing number of users. Also, a new technology standalone can be a single point of failure. For this reason, we should embrace alternative wireless networks as a complementary service to support high bandwidth and low cost in congested urban areas. Song and Jamalipour (2004) work with a different mechanism of selection to integrate cellular and wireless LAN networks. They introduced a network selection algorithm combined with analytic hierarchy process (AHP) and grey relational analysis (GRA), what is another type of multi-attribute decision making (MADM) technique. Kushwaha and Ratneshwer (2016) also uses AHP in congestion control problem as a decision making to select appropriate approach for a particular network environment. The work of Jayakumar et al. (2019) uses multi criteria decision making (MCDM) scheme to calculate weight to increased average lifetime energy of network nodes. The Higuchi and Altintas (2018) paper, they design an intelligent interface selection mechanism adapted to hybrid V2V communications. They suggest a method of hierarchical decision making in which a remote central server loosely controls interface selection by vehicles. The server provides a suggested interface selection scheme based on the statistically previous learning about network and route status. Differently, in this work, we focus on V2X communication, assuming that vehicles can select independent and dynamically different options of network radio to transmit their information without depending on a central server.

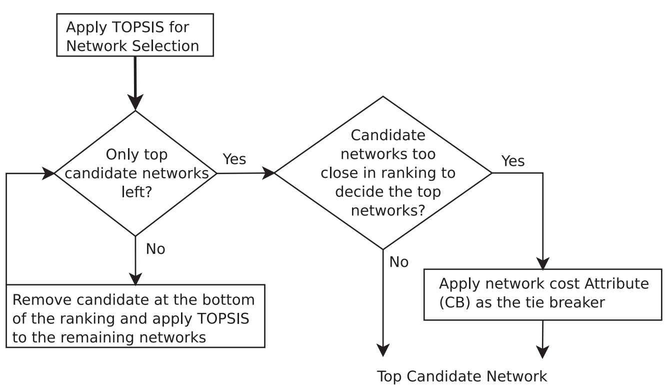
Cooperative cellular networks can be enhanced by using social information of users in the network. A cooperative transmission algorithm using fuzzy QoS gateway selection was proposed in Zhioua et al. (2015). They use vehicular ad hoc LTE-advanced (LTE-A) with hybrid network system that determines a gateway to join the originate vehicle to the base station (BS) under V2I communications, this means that a different scenario from our work and their system risks being a single point of failure. Khwakhali et al. (2020) proposed a midpoint relay selection scheme that increases average throughput of device to device (D2D) communication between users in the network leveraging social trust among nodes while selecting a relay node.

To determine the best network option the vehicle has for transmitting data, we compare two different algorithms and analyse their performance by introducing a new knowledge, which is the route information the driver plans to use. This does not mean that the driver cannot change his initial route program. In this case, this route transition interval may be sensitive to data loss. We consider that it may have a low probability of happening and do not take into account this transition. In this paper, we compare two algorithms to select the optimum network. TOPSIS is a well-known algorithm, and we consider the approach made by Bari and Leung (2007b) and the SISS algorithm that is a scheme based in service (Teixeira and Huszak, 2019). Next, we will illustrate the algorithms.

3.1 TOPSIS

Several algorithms have been proposed by the scientific community to classify candidate networks. This type of approach is deterministic and has been widely used in decision-making procedures, where results impact on various elements. Technique for order of preference by similarity to ideal solution (TOPSIS) is a type of multiple attribute decision-making (MADM) approach and can be used for different purposes (Bari and Leung, 2007a; Kushwaha and Ratneshwer, 2016; Jayakumar et al., 2019). In the article by Bari and Leung (2007a), the authors apply TOPSIS to the network selection dilemma. Nevertheless, they identified some abnormalities that occurred in the TOPSIS algorithm and proposed a review, where they considered only the most important alternatives in the decision system. It is an iterative approach that applies the TOPSIS algorithm and, after each new iteration, eliminates the bottom option, thus eliminating anomalies. Simulation results show that the proposed algorithm could enhance the throughput of the connections solicitations and reduce the price-cost per bit of data transfer. Due to this reason, we adopt this technique to implement our selection scheme proposal in this work. In the next session, we will present how the algorithm works and show the equations used in this work. The TOPSIS algorithm can be visualised in Figure 1.

Figure 1 TOPSIS algorithm process



Source: Bari and Leung (2007a)

To address the network selection problem, the corresponding authors consider the following attributes in the decision-making procedure (Bari and Leung, 2007b):

- Cost per byte transmitted (*CB*): Cost of transport bytes of the access network, such as the use of frequency spectrum and the roaming agreement with the operator.

- Bandwidth (*BW*): Available bandwidth on the access channel of a certain technology.
- Allowed bandwidth (*AB*): Specifies the bandwidth provided by a user.
- Utilisation (*U*): Summation of current utilisation of the wireless channel.
- Delay (*D*:) Average time to transmit the packet in the access channel.
- Jitter (*J*): Average delay variations in the access channel.
- Packet loss (*L*): Average packet loss rate in the access channel (packet loss probability).

With this sequence of attributes, a matrix with N elements is built. Each element represents one network that will be considered in the selecting process. The matrix NW_N can be represented as follows:

$$NW_N = \begin{bmatrix} CB_1 & BW_1 & AB_1 & U_1 & D_1 & J_1 & L_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ CB_N & BW_N & AB_N & U_N & D_N & J_N & L_N \end{bmatrix}$$

The TOPSIS algorithm modification summary steps:

- Firstly, we normalise the values of each attribute in the *NW* matrix to adjust the values entered in the matrix at different scales. We used a column normalised matrix technique; it represents each column as C in the equation (1).

$$(C_{norm})_i = \frac{C_i}{\sqrt{\sum_{i=1}^{N} C_i^2}} \tag{1}$$

- Attribute weight (*w*) – Assigning weights to different parameters in the algorithm plays a key role in network selection. It should be based on the interpretation of application requirements to assign the appropriate weights, and the sum of all weights used in each line must be one, as shown in the equation (2).

$$\sum w_{[CB,BW,AB,U,D,J,L]} = 1 \tag{2}$$

- Then the weights (*w*) of each of the attributes involved in the selection decision are determined according to their degree of importance, as represented in equation (3). In our simulation, this represents the requirements of each application.

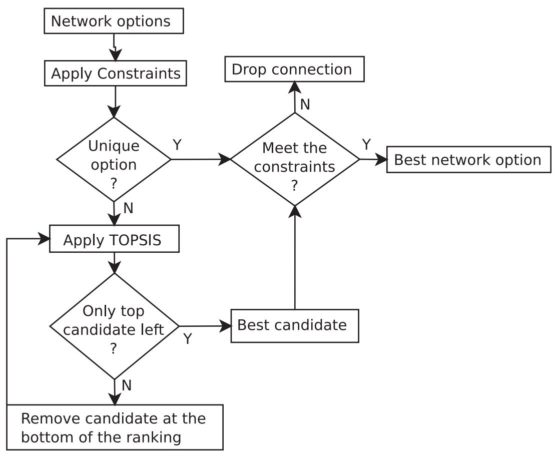
$$(C_{update})_N = (C_{norm})_N * w \tag{3}$$

- The values for each attribute are calculated. Depending on the attribute, the best value can be the maximum or minimum value. For example, in the latency's case attribute, the best value will be the lowest and the worst value is the highest. For the case of a bandwidth related attribute, however, the logic is opposite.

- For each network option analysed (represented by a line in the *NW* matrix), we calculate the proximity and outlying measures for the best and worst cases using Euclidean distances. Then calculates the *P* preference level, based on relative proximity for the best values and, for the worst values, the separation.
- Finally, it selects the access network with the highest *P* value.

However, applying this algorithm to select networks in the V2X environment communication, where we have high mobility and congested systems, we realise that modification in the TOPSIS algorithm is not enough to select the best network option. For this reason, we introduce a new complementary change, and this solution is named as SISS, explained in the next section.

Figure 2 SISS algorithm



3.2 *Service-based interface selection scheme*

The service-based network selection algorithm is based on a modification of the TOPSIS method applied in network selection. The SISS algorithm comprises four steps. It is assumed that vehicles and RSUs are equipped with multiple network interfaces such as 5G-NR or 4G-LTE or 3G-UMTS as cellular network and 802.11p as DSRC, and these networks can be active simultaneously. At the beginning of the process, before executing the network selection algorithm, the constraints and requirements that each type of service has are defined and a matrix with updated network status is also built. The changeable values of the simulation are the *bandwidth channel*, *allowed bandwidth* and *utilisation* parameters that will be described below. The following constrains are set in the simulation environment:

- If over 1 km away, release option DSRC 802.11p (default distance range limit of the technology).
- If the network option does not support the requirements (for example, bandwidth), discard this option and run the algorithm again; if there is no other network option, drop the connection.

- If there is only one option, and this network meets the application's requirement, it is unnecessary to execute the algorithm; it will choose the available exclusive network.
- If no network is available or if the networks do not support the requirements, drop the connection.

Figure 2 introduces the SISS algorithm.

The key applications that will be used in C-ITS communications are assumed to be: V2X data, information formed by road safety applications, are the cooperative awareness message (CAM) and decentralised environmental notification message (DENM) packages (Machardy et al., 2018), as well as the traditional data types that travel on the internet such as data (web and file transfer), video and voice over IP. The following describes the weights (w) of different attributes for common application types.

- Data packet – Traditional web application that usually requires low QoS parameters. Attributes such as delay, jitter, packet loss, and bandwidth are not critical, but the cost of information traffic needs to be considered.
- V2X packets – Is a low bandwidth signal used for C-ITS connections that requires high QoS and no packet loss. Khilar and Bhoi (2014) describe some applications that would allow the use of high level QoS regardless of the network traffic costs.
- VoIP packets – Requires low bandwidth but is sensitive to delay and instability but can withstand small packet loss. Total bandwidth is not an important factor, but a higher weight is used for bandwidth utilisation because there is a strong correlation between jitter and delay.
- Video packets – Types of multimedia applications, e.g., streaming, where they require more bandwidth than VoIP. Bandwidth, transport cost and current usage are important parameters. However, parameters such as delay and instability have a lower weight.

An important phase of our proposed algorithm is to analyse the constraints and application requirements of each new information that will be transmitted on the channel. Thus, it is possible for the data source to choose the best network alternative available at that time without depending solely on the carrier choice. Thus, it is also possible to ease the work of the service provider. The SISS method is represented in Algorithm 1.

For the reason of comparison in the performance of the proposed algorithm, the summation of the bandwidth of all networks will be used in our simulation, and it is called as *Aggregate_Bandwidth*, as shown in equation (4):

$$Aggregate\_Bandwidth = \sum_{i=1}^{N} CB_N \tag{4}$$

Algorithm 1 Steps of the SISS algorithm

Input: Available network options
Output: Network selected
Step 1:
Define weights of the attributes

Define the constraints
Filter interfaces (constraints)
Step 2:
Select interface using TOPSIS algorithm
Step 3:
Verify if the interface selected meet the constraints
if Not Discard the interface selected **then**
Repeat *Step 2*
end if
Step 4:
if The interface selected meet the constraints **then**
Choose this network option
if Any interface meet the constraints **then**
Drop the connection
end if
end if
END of algorithm

4 Simulation

The road traffic simulator simulation of urban mobility (SUMO) (Behrisch et al., 2011) was used to make the traffic of vehicles present in the tests. The map used on the simulation is the downtown of Budapest city (Hungary) represented on Figure 3.

Figure 3 SUMO simulation – Budapest Downtown map (see online version for colours)

In this work, we do not need a precise physical, mac or network model, we just use general values for delay, jitter and bandwidth. Therefore, we implement a simplified data communication procedure in Python programming language to compare the different algorithms.

The simulation lasted for 10^3 seconds, and the vehicles used random trip routes. To establish communication between moving vehicles, the standard specified in Table 1is adopted. The connections are randomly chosen and uniformly distributed over the total simulation time.

Table 1 Simulated data type

Connection types	*Bit rate Kbps*
V2X	512
DATA	8,192
VIDEO	10,240
VOIP	1,024

The time for each connection uses Gaussian distribution, following the pattern in Figure 4. Different time distribution is used, which means that connections start and end at a random time. This was necessary to simulate a real environment, always trying to congest the total bandwidth available. Figure 4 represents two groups. The first group

a Video time distribution, when we change the mean in 30, 60, 90, 120 and 150 seconds, and the second group.

b Voice time distribution, when we change the mean of the voice distribution following the same pattern, 30, 60, 90, 120 and 150 seconds.

As part of the network traffic model used in this research, the purpose of these distribution changes is to measure the different behaviours between algorithms when changing application requirements.

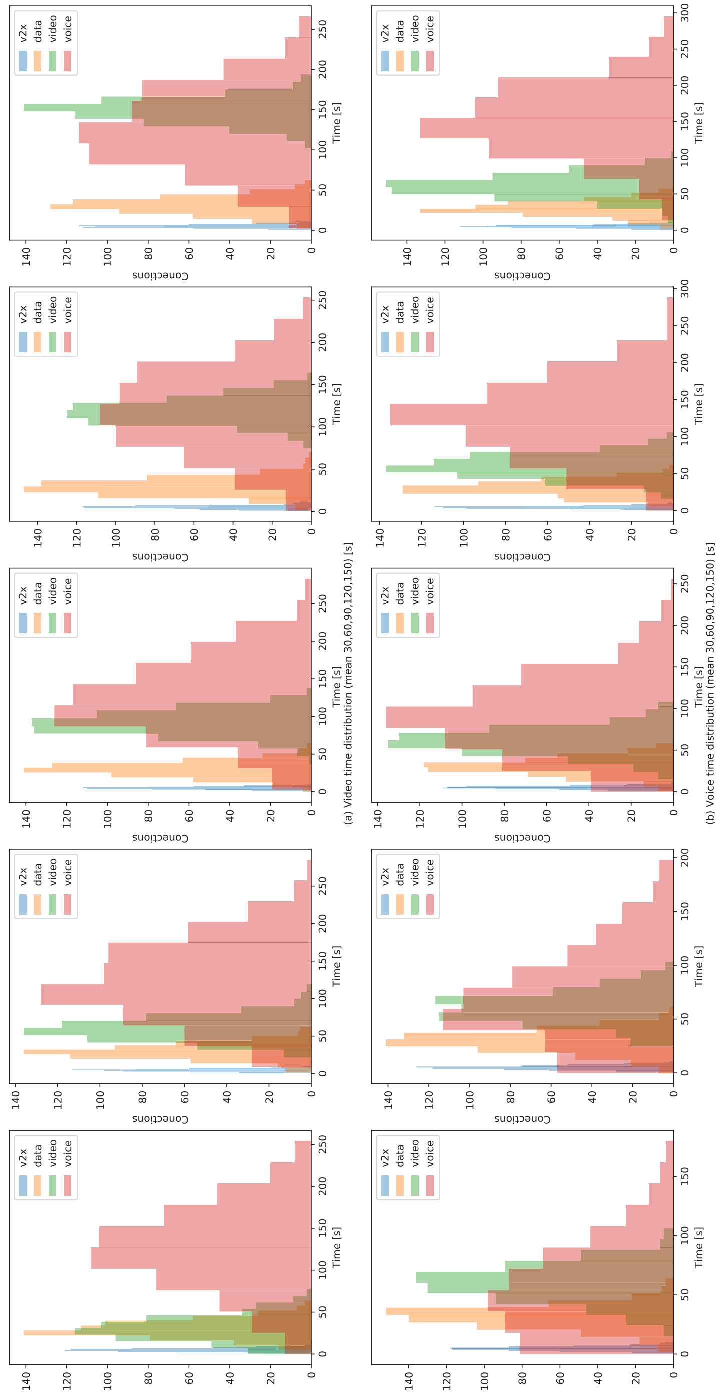
Table 2 Attribute for the candidate networks

	CB (%)	*BW (Mbps)*	*AB (Mbps)*	*U (%)*	*D (ms)*	*J (ms)*	*L (10^{-6})*
5G-NR	100	200	10	0	50	15	10
4G-LTE	30	50	2	0	100	20	15
3G-UMTS	100	40	0.2	0	200	50	25
DSRC 802.11p	40	50	5	0	150	30	20

Table 3 Weights

	CB	*BW*	*AB*	*U*	*D*	*J*	*L*
w_{data}	0.25	0.2	0.2	0.2	0.05	0.05	0.05
w_{V2X}	0	0	0	0.1	0.4	0.4	0.1
w_{video}	0.2	0.1	0.1	0.1	0.2	0.2	0.1
w_{voice}	0.2	0	0.1	0	0.3	0.3	0.1

Figure 4 (a) Video (b) Voice time data distribution (see online version for colours)



To analyse the differences in algorithms, four networks are considered in the simulation. Table 2 indicate the attribute values for these networks at the time of selection. As described in the 3GPP (2019) section, these attributes must be given by the infrastructure telecom operator as a requirement of the QoS contract. These values are just an initial example used in our simulation, and may vary for each different scenario or if network specifications vary.

The following weights applied in our simulation are described in Table 3. This represents the importance of each data type when selecting the network option. When the value is zero, this parameter has no relevance at the time of running the algorithm.

At each new interaction, the system updates the utilisation value $U(\%)$ of the networks. A key step in the efficiency of the proposed algorithm is the definition of constraints that each new connection will establish before choosing the best available network option. In this work, tree methods are applied. In the first method, we do not interfere with the choice of the network. It randomly chooses a network without knowing if this option would or would not meet the application requirements. This method is called RANDOM.

The second method, only the starting position information of the vehicles is available from the GNSS system. Therefore, only the initial distance between the vehicles is calculated. This method is identified as start distance (SD). The calculation of the Euclidean distance, latitude (X) and longitude (Y) values of each vehicle is applied, according to equation (5).

$$SD = \sqrt{(X_{car1} - X_{car2})^2 + (Y_{car1} - Y_{car2})^2} \tag{5}$$

In the third method, a simulation is performed when beside the initial vehicle position, the route information that the driver intends to follow is available from the GNSS system. With this, it is possible to calculate the maximum distance (MD) between vehicles during the transmission time of the data. This calculation is shown in equation (6) and identified as MD.

$$MD = \max(\sqrt{(X_{car1} - X_{car2})^2 + (Y_{car1} - Y_{car2})^2}) \tag{6}$$

4.1 Evaluation

In connected mobile network environments, devices typically transfer data on the network where they are already connected at the time of application request. The source host has no control at the time of selecting the network. That is, the task of choosing the best alternative for the user is done by the access service provider. This often causes problems with data transmission interruption, such as link breakage or handoff. Also, the application is whispering for not meeting the requirements of QoS. From now on, as the user has different connection options, our proposal is for the host to stay connected throughout the available access network and use our intelligent network selection algorithm, applying the restrictions required by the applications. Thus, it is possible to select the best access network to transmit the data of a given application.

To show the efficiency of the proposed algorithm, five simulations were performed, with 150, 250, 350, 450 to 550 random requests and equally distributed in data, voice, video and V2X signal, as described in the simulation chapter. It can be analysed that when applying the restriction techniques in each connection and using the selection algorithm, we have a more efficient use of the total bandwidth sum of all networks available to users. In addition, we use different time distribution of voice and video packages, as we can see in Figure 4, because we believe these two services are the most complicated applications that can easily overload the system's bandwidth.

Figure 5 Discarded packet comparison (see online version for colours)

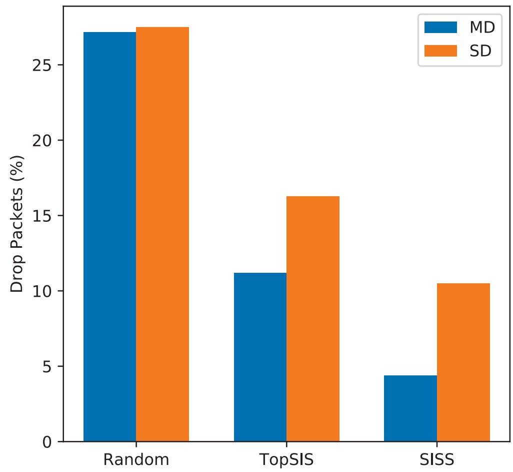
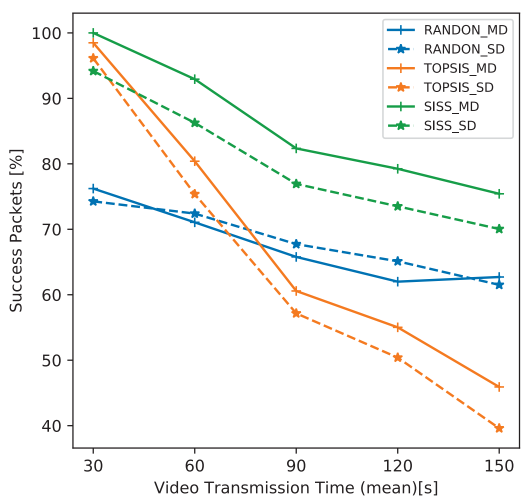


Figure 6 Success packets ratio with different video transmission time (see online version for colours)



We have two columns in Figure 5: SD and MD. As explained in the description of the simulation environment, SD basically uses the actual position of the cars and MD uses the route information that the driver intends to use (GNSS) as a complement to the network selection function. It can be said that this is a cross-layer technique. We have three groups of comparisons called RANDOM, TOPSIS and SISS. These are the names of the algorithms used in the simulation, already explained on the simulation session.

Figure 7 Success packets ratio with different voice transmission time (see online version for colours)

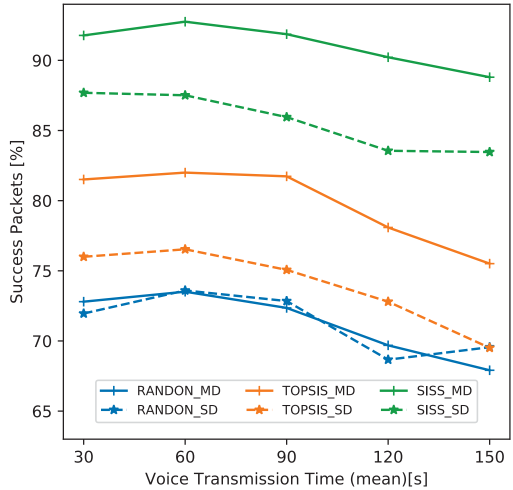
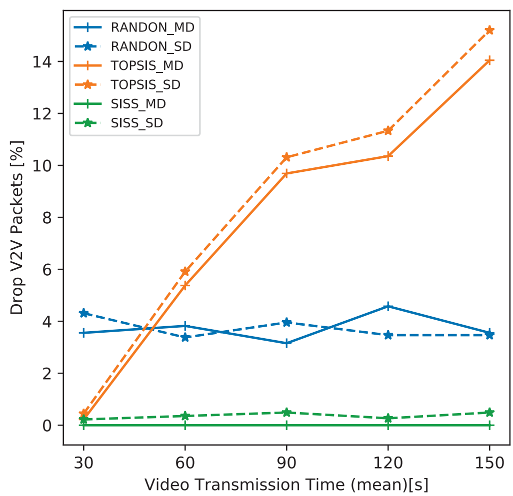


Figure 8 V2X drop packets ratio with different video transmission time (see online version for colours)



In a congestion simulation, we can reduce the drop of packets from 27% using RANDOM to 15% using TOPSIS and 10% using SISS algorithm, when we just use the initial position (SD algorithm). But when we know the route information, we are able to abruptly reduce the drop data packets from 26% of RANDOM to 10% in TOPSIS and 4% with SISS. After that, we analyse the success packet ratio when changing the Gaussian distribution mean of the video and voice applications. Figure 6 shows the total successful packets transmitted in percentage when we change the mean of the video with 30, 60, 90 120 and 150 seconds of transmission time. We realise that with short videos of 30 seconds on average, we have no differences between the algorithms. However, while we are increasing the average time of transmission of the videos, the differences are significant, reaching a 50% improvement, using the SISS. And the TOPSIS algorithm can get worse even if uses RANDOM choice. The same approach was applied with the voice data, and the results are shown in Figure 7. There are no significant changes in this case because the requirements of the application are not high, as in the video packets.

Figure 9 V2X drop packets ratio with different voice transmission time (see online version for colours)

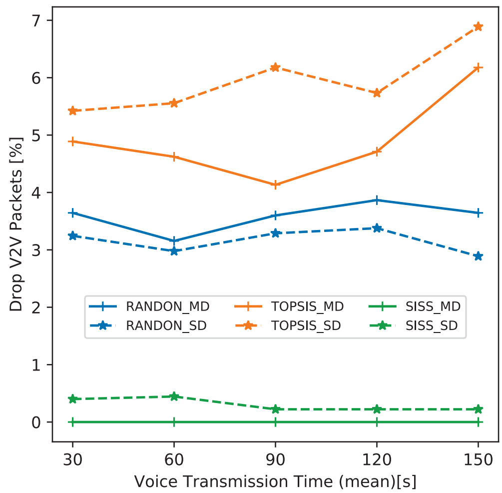
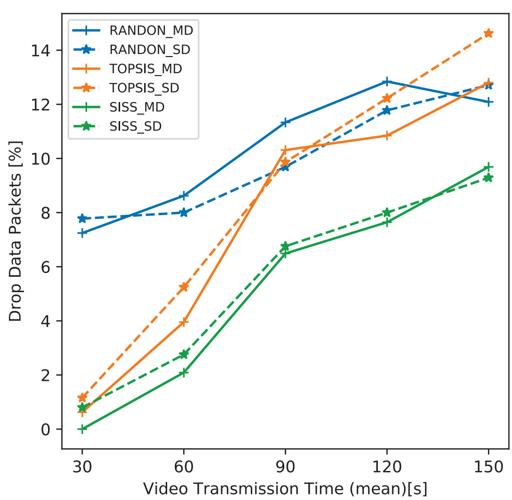


Figure 10 Data drop packets ratio with different video transmission time (see online version for colours)



Figures 8 and 9 show us the V2X drop packets transmitted in percentage when we change the mean of the video and voice transmission time, respectively. In these two figures, we can visualise that we have a better control of the QoS when we use the SISS algorithm proposed.

Figure 11 Data drop packets ratio with different voice transmission time (see online version for colours)

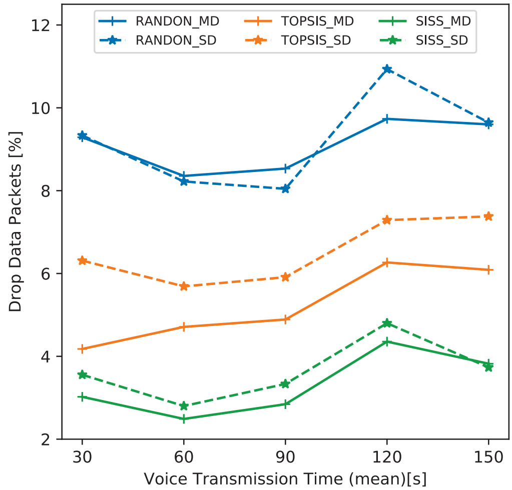
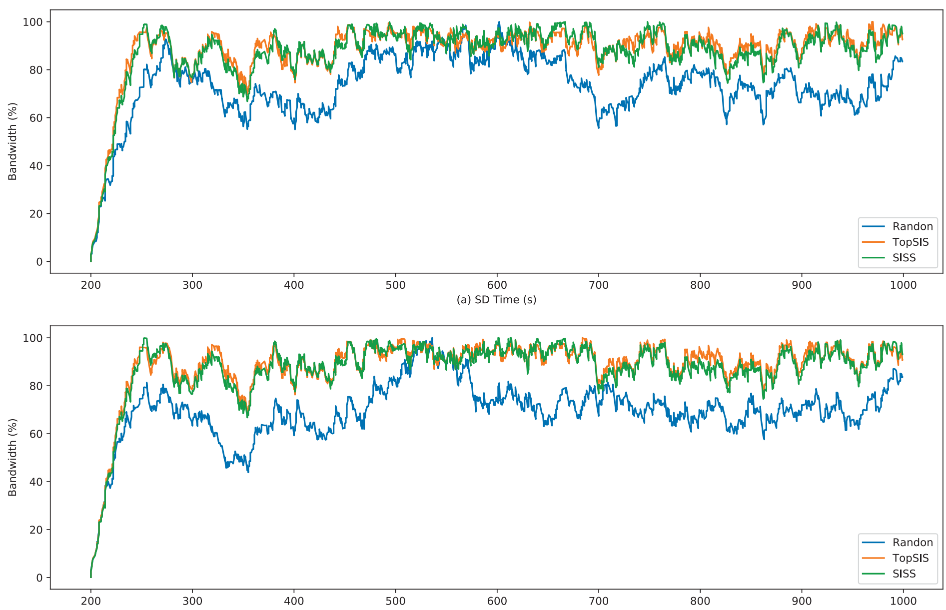
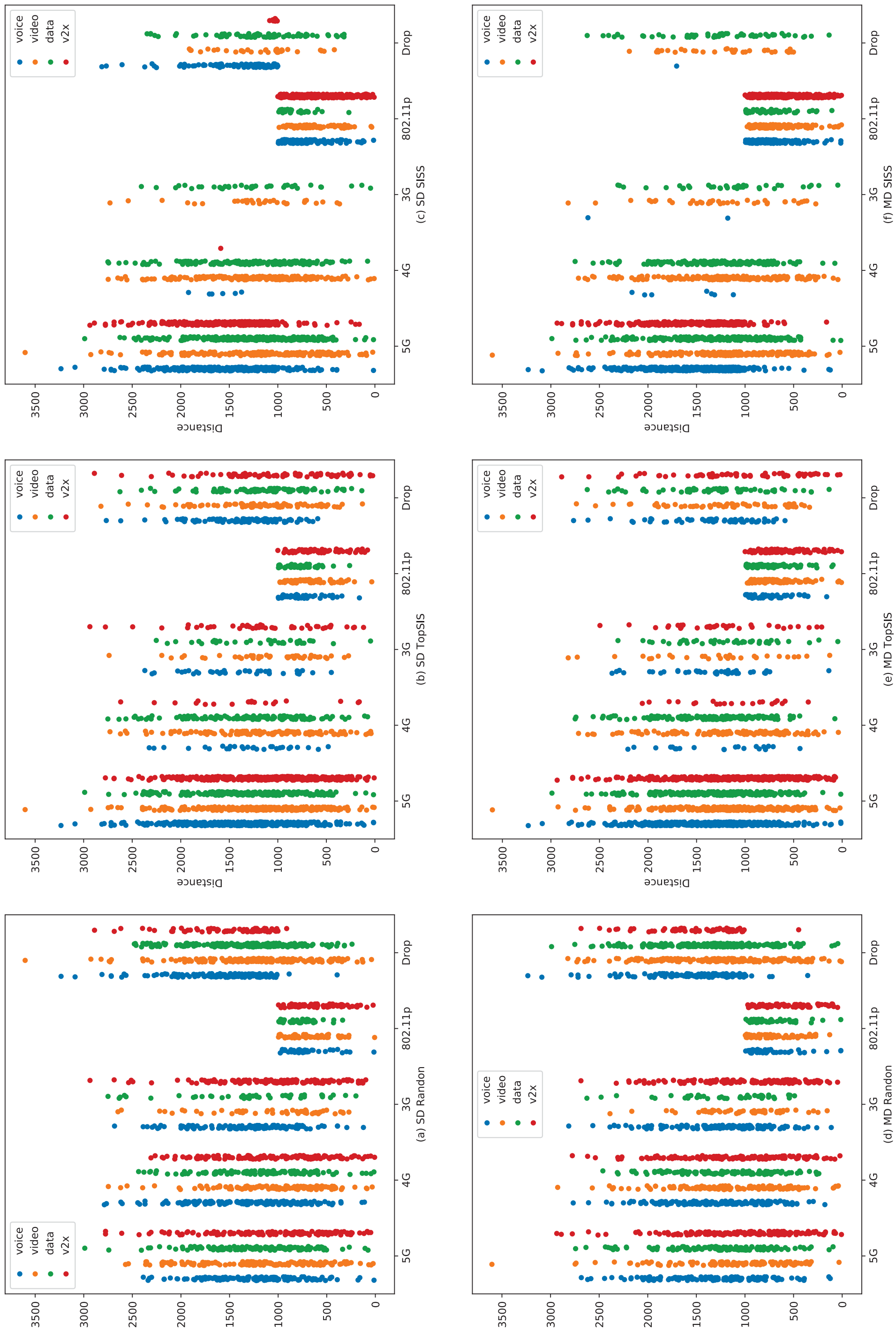


Figure 12 Bandwidth utilisation with (a) SD (b) MD algorithm (see online version for colours)



Figures 10 and 11 show us the data drop packets transmitted in percentage when we change the mean of the video and voice transmission time. These types of packets suffer more loss compared with V2X packets, but this is acceptable because the requirements are smaller, and it has more tolerance to retransmissions.

Figure 13 Applied QoS – data type per interface (see online version for colours)



In Figure 12, one can observe the bandwidth when applying the SISS and TOPSIS techniques with both MD/SD methods. While there are no apparent differences in aggregate bandwidth usage, it is important to note that the real gain is in service differentiation, which will be shown in Figure 12.

Figure 13 summarises what happened in our simulation. We have three groups of interface selection (RANDOM, TOPSIS and SISS), split in two rows. The first row shows the simulation using the SD method, while the second row shows the MD method. This figure demonstrates in which interface the different types of packets are being transmitted, making a correlation between the distance of the hosts involved in the transmission. The last column of each figure illustrates the dropped packets. In all simulations it is easy to see that the 5G interface is the most used, since it has the best parameters used in the network selection, such as higher bandwidth and lower latency.

However, it is clear that the other access technologies are important to help the entire system meet the application requirements. For example, in the RANDOM selection algorithm, the distribution of the packets is uniform distributed. Just in the 802.11p network, due to the distance limit range, we do not see traffic data after 1 km. In the TOPSIS and SISS algorithm, we can visualise that the short-range communication is concentrated in the 802.11p network, and it distributes the remaining packages on the other networks. The best expectation of this work is shown in figure MD SISS (f), where we can visualise the effectiveness of the SISS algorithm where we can reach fewer drop packets, especially in V2X packets that are essential for enabling communication between vehicles, especially in safety applications.

Therefore, we can demonstrate the efficiency and improvement of data transmission by applying the cross-layer technique. Here, we use the position information of the navigation route, already available in vehicle GNSS systems, and not just common parameters when addressing communication networks such as jitter, latency and bandwidth.

5 Conclusions

The next generation of mobile network communication systems should work collaboratively to provide the sense of unlimited bandwidth with impressive speeds, and excellent performance compared to currents networks to attend the C-ITS requirements. One way to achieve that improvement in our future wireless infrastructure is to use multiple networks simultaneously and apply intelligent algorithm when determining the suitable network available at that moment, to meet the requirements of the applications. Decentralising the service control of telecommunication operators and giving more flexibility when deciding which interface the application will use, we can have a higher probability to guarantee the success of the connection. As a result, the users and systems could have a perception of the unlimited bandwidth available for their applications. This is one of the implications of our proposed work. These features will allow new types of applications, such as autonomous vehicles, which are currently unfeasible because of the limitations of current vehicular communication systems. Future connected vehicles will improve their entire environment, such as traffic management, less traffic accidents and fatalities, and fuel efficiency, as it will be possible to provide real-time information for intelligent systems to take appropriate action. But for this to become possible, today's radio technologies must cooperate with emerging technologies and not just replace technologies with new ones. Thus, it is possible to form an efficient and heterogeneous network environment. The main goal of this research is to address the use of an intelligent selection network scheme together with the navigation route position information to predict and select the best network infrastructure available at a certain time. Applying this technique also relieves the work of the service provider, and the source transmitter has more autonomy when choosing the network, checking if it can meet the application QoS requirements. We also present and analyse the techniques, called MD and SD, and present the advantage when using cross-layer information available in other applications than just usual network parameters to select and use network access to transmit the data application. The experimental results show that the use of the proposed strategies allow not only an increase in connectivity, but also a better utilisation of the available bandwidth in a heterogeneous network. The proposed SISS algorithm proved to have a better performance, either in the amount of discarded packets or in the efficiency of using network bandwidth in different scenarios. This is because of the cross-layer information technique, using the GNSS information. The challenge now is to put into practice the implementation of this algorithm so that performance is tested in real applications scenarios. This work also can be extended to carry out feasibility studies on the implementation solution in terms of scalability in different mobility and density scenarios. In addition, it is possible to evaluate the use of learning algorithms to build intelligent grid selection algorithms based on application standards. The recognition of patterns and the relationships of mobility, networks and application requirements can allow the development of more robust and precise strategies that satisfactorily meet the needs of users. In order to further improve the proposed algorithm, the best effort approach can be analysed that allows the user to connect the network that offers the best conditions. When it does not meet the restrictions, queuing techniques can be applied, to manage the delivery of packages, minimising the need for retransmissions. Therefore, the network selection schemes can be a transitional method, while the full implementation of network layer mobility is not yet ready.

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