FEDERAL UNIVERSITY OF PARÁ
INSTITUTE OF TECHNOLOGY
POSTGRADUATE PROGRAM IN ELECTRICAL ENGINEERING

IAGO LINS DE MEDEIROS

QOE AND QOS-AWARE HANDOVER FOR VIDEO TRANSMISSION IN HETEROGENEOUS VEHICULAR NETWORKS

DM: 14/2018

UFPA / ITEC / PPGEE
Guamá University Campus
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Dissertation submitted to the Judging Committee at the Federal University of Pará as part of the requirements for obtaining a Master's Degree in Electrical Engineering in the area of Applied Computing.

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INSTITUTO DE TECNOLOGIA
PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA ELÉTRICA

"QOE AND QOS-AWARE HANDOVER FOR VIDEO TRANSMISSION IN HETEROGENEOUS VEHICULAR NETWORKS"

AUTOR: **IAGO LINS DE MEDEIROS**

DISSERTAÇÃO DE MESTRADO SUBMETIDA À BANCA EXAMINADORA APROVADA PELO COLEGIADO DO PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA ELÉTRICA, SENDO JULGADA ADEQUADA PARA A OBTENÇÃO DO GRAU DE MESTRE EM ENGENHARIA ELÉTRICA NA ÁREA DE COMPUTAÇÃO APLICADA.

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Dedico este trabalho a Deus e minha amada família.
I dedicate this work to God and my beloved family.

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“May the wind under your wings bear you where the sun sails and the moon walks,” answered Gandalf, who knew the correct reply.

J. R. R. Tolkien

Resumo

Resumo da Dissertação apresentada à UFPA como parte dos requisitos necessários para obtenção do grau de Mestre em Engenharia Elétrica.

QoE and QoS-aware Handover for Video Transmission in Heterogeneous Vehicular Networks

Orientador: Prof. Dr. Eduardo Coelho Cerqueira
Palavras-chave: Handover; QoE; VANET; Heterogeneous.

Redes Veiculares (VANETs) oferecem uma ampla gama de serviços multimídia que vão desde alertas de segurança a vídeos de entretenimento e publicidade. Neste contexto, os usuários podem acessar o conteúdo através da comunicação Veículo-para-Infraestrutura (V2I), que pode considerar diferentes redes sem fio, tais como LTE, Wi-Fi, etc. No entanto, transmissão de vídeo em uma VANET com qualidade de Experiência (QoE) e Qualidade de Serviço (QoS) é uma tarefa desafiadora, devido à alta mobilidade do veículo que causa falhas de comunicação com a infraestrutura. Para mitigar tais fatores, esta dissertação de mestrado apresenta um algoritmo de *handover* que considera QoE, QoS e qualidade do canal em redes heterogêneas, chamado de *handover* ciente de Qualidade de Serviço, Experiência e Rádio (SER). O algoritmo proposto considera o *Analytic Hierarchy Process* (AHP) para ajustar o grau de importância de cada critério na escolha da estação rádio base apropriada que o nó móvel deve se conectar, permitindo uma decisão de *handover* mais eficiente para transmissão de vídeo com suporte a QoE. Resultados de simulação constatam que o *handover* SER entregou vídeos com QoE 15% melhor comparado aos algoritmos encontrados na literatura.

Abstract

Abstract of Dissertation presented to UFPA as part of the requirements for obtaining a Master's Degree in Electrical Engineering.

QoE and QoS-aware Handover for Video Transmission in Heterogeneous Vehicular Networks

Advisor: Ph.D. Eduardo Coelho Cerqueira
Key words: Handover; QoE; VANET; Heterogeneous.

Vehicle Ad Hoc Networks (VANETs) offer a wide range of multimedia services ranging from safety and traffic warnings to entertainment and advertising videos. In this context, users can access content through vehicle-to-infrastructure (V2I) communication, which may consider different wireless networks, such as, LTE, Wi-Fi, etc. However, video streaming at a VANET with Quality of Experience (QoE) and Quality of Service (QoS) is a challenging task, due to the high vehicle's mobility that causes communication failure with the infrastructure. To mitigate such factors, this master's dissertation presents a handover algorithm that considers QoE, Quality of Service (QoS) and channel quality in heterogeneous networks, known as handover aware of Quality of Service, Experience and Radio (SER). The proposed algorithm considers the Analytic Hierarchy Process (AHP) to adjust the degree of importance of each criteria in choosing the appropriate radio base station that the mobile node must connect to, allowing a more efficient handover decision for video transmission with QoE support. Simulation results show that SER handover delivered videos with QoE 15 % better compared to the algorithms found in the literature.

Contents

List of Abbreviations

3GPP	3rd Generation Partnership Protocol
ABC	Always Best Connected
AHP	Analytic Hierarchy Process
AP	Access Point
BS	Base Station
CBR	Constant Bit Rate
CI	Consistency Index
CR	Consistency Ratio
DSRC	Dedicated Short-Range Communication
eNB	Evolved Node B
GOP	Group of Pictures
HO	Handover
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transport Systems
LTE	Long Term Evolution
MAC	Media Access Control
MIH	Media Independent Handover
MME	Mobility Management Entity

MOS	Mean Opinion Score
MSE	Mean Squared Error
MSU	Moscow State University
NS-3.27	Network Simulator
OBU	On-Board Unit
PDR	Packet Delivery Ratio
pMOS	Predictive Mean Opinion Score
PSNR	Peak Signal-to-Noise Ratio
QoE	Quality of Experience
QoS	Quality of Service
RCI	Ratio Consistency Index
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RSU	Roadside Unit
SGW	Serving Gateway
SINR	Signal-to-Interference-plus-Noise Ratio
SSIM	Structural Similarity
SUMO	Simulation of Urban Mobility
UE	User Equipment
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VANETs	Vehicular Ad Hoc Networks
VQM	Video Quality Metric
VQMT	Video Quality Measurement Tool
WAVE	Wireless Access in Vehicular Environments

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CHAPTER 1

Introduction

1.1 Overview

Video transmissions are generating a great demand in the area of data transmission, accounting for 73% of Internet traffic [1], especially in wireless networks. This demand is generated by users consuming new video applications, ranging from security footage up to live entertainment videos [2]. Today, users produce, share and consume real-time video services, even in their own vehicles.

Currently, Vehicular Ad Hoc Networks (VANETs) have increased their interconnection capacity, *i.e.,* in addition to Vehicle-to-Vehicle (V2V) communication capability, it is also being designed to communicate with infrastructure networks (Vehicle-to-Infrastructure - V2I) [3]. This infrastructure can be composed of metropolitan, *e.g.,* Long Term Evolution (LTE), and local wireless networks, widely used in urban environments, allowing a greater transmission capacity over a large coverage area.

This infrastructure needs to keep the good provision of Internet access for the consumer users, by using a good handover process. Handover (also known as handoff) is characterized by the transfer from an ongoing data session from one station to another. Handover is an essential resource in telecommunication systems, especially at cellular or wireless data networks with mobile users. The good performance of the handover enables a high quality in video transmission for the users. So it is an essential component that needs special attention from the industry and academia.

Also the projection of video consumption in Internet is expected to keep at a fast growth rate. However, certain quality level should be meet for the users. Besides the greater demands of resources consumption to the telecommunication industries, the VANET-based users are becoming more rigorous as well.

1.2 Motivations and challenges

The mobile infrastructure can have distinct characteristics (*e.g.,* microcell, picocell, etc.) to reduce high data traffic at macrocells. Due to limited infrastructure coverage, vertical or horizontal handovers can occur frequently. The mobility is also a factor that aggravates the handover performance [4] since the nodes are the proper vehicles. Depending on its speed, a vehicle can travel across several different geographical areas in a short time interval, forcing it to frequently execute handovers so that it can maintain connectivity with the video service [5].

Besides the hard scenario generated by vehicles, other problems can be associated, such as a wrong handover execution that occurs when a bad decision is performed. Beyond all these challenges, the mobility of vehicles and users also impose the need for seamless handover. Originally traditional handover algorithms, such as Media Independent Handover Services (MIH), only considered signal strength received by the user device, but this approach is no longer efficient for video dissemination and to achieve good Quality of Experience (QoE) levels [6]. Due to this, there is a need to select QoE and Quality of Service (QoS) parameters at handover decision level to enable more feasible handover execution.

In this way, the handover must take into consideration the user satisfaction requirements *i.e.,* QoE, with the content player, where users expect to watch videos without any interruptions, ghosting, blocking, pixelization, freezing frames, and at a certain quality level no matter what changes may occur in the networking environment [7].

In addition, the heterogeneity of Radio Base Stations (BS) also turns the process harder for the reason of its distinct characteristics, such as transmission power, coverage area, higher interference, network densification, among other things. Every handover results in a high signaling overload for the involved BS and its execution must be carefully executed. Therefore, there is a need to have a good handover algorithm.

QoE-aware decision-making algorithms improve overall network performance based on user perspective, and it is very sensitive to any packet loss (*e.g.,* video frames). This brings benefits not only to the user, but also to all stakeholders involved in video services provisioning [7]. However some existing works just address QoE only as a performance metric rather than as an input parameter for the handover decision. QoS can be a great complement for the handover decision. QoS acts as a estimator for the network services quality, *e.g.,* loss rate, jitter, delay. The use of this distinct parameters of QoE and QoS in addition to signal strength information can help the handover algorithm in VANETs to make a better decision, but there needs to be an approach for how it can relate distinct and often conflicting criteria.

In this context, there are several techniques for answering to the decision problem of Multiple Criteria Decision Making (MCDM) to choose where a node must perform handover to keep videos with a good quality. The Analytic Hierarchy Process (AHP) [8] is a technique that decomposes a complex problem into a simpler hierarchy of sub-problems.

The AHP combines qualitative and quantitative factors for the analysis, and can be a good option to produce a suitable solution when multiple parameters are considered in the handover process.

1.3 Objectives

This master's dissertation presents a QoE/QoS-aware handover algorithm for video dissemination at heterogeneous VANET scenarios called SER Handover. The proposed algorithm considers Reference Signal Received Power (RSRP) as signal strength parameter, Packet Delivery Rate (PDR) as QoS component, and Predictive Mean Opinion Score (pMOS) from QoE.

Through the use of AHP, the proposed SER algorithm is able to assign different degrees of importance to each parameter. And each distinct base station is evaluated by AHP. The BS with the highest AHP score is selected as the most suitable cell to receive the handover. We conducted simulations to evaluate the performance of the proposed SER handover algorithm to disseminate videos at heterogeneous VANET scenarios compared to other traditional handover algorithms.

Thus, the objectives of this work includes:

- Study the essential elements of handover in VANETs to guarantee high communication quality, especially at mobile users scenarios such as vehicular.
- Present the main handover algorithms for VANETs.
- Evaluate the performance of the proposed handover algorithm compared to other handover algorithms at video dissemination in heterogeneous VANET scenario.

1.4 Contribution

This work has the following main contributions:

- Development of a QoE/QoS-aware adaptive handover algorithm
- Advances the state-of-the-art in handover algorithm for VANETs
- Implements and evaluates the proposed algorithm
- Motivates the sharing of video content with QoS/QoE support in VANETs

1.5 Text Organization

The rest of this dissertation is organized following the ordering described below:

- Chapter 2: Presents an overview on VANETs that acts as the main scenario for the proposed handover algorithm, the QoE assessment and its metrics are better discussed, AHP is explained as the foundation for the proposed SER handover algorithm and a broad explanation about handover is discussed.
- Chapter 3: Presents some existing handover algorithms for vehicle and mobile scenarios. The advantages and disadvantages of each of these proposals are described, as well as the related works associated.
- Chapter 4: Details the proposed SER handover mechanism, its architecture and how it works.
- Chapter 5: Some use cases for applying the proposal are described. It also presents the parameters that are used in the simulations, as well as the simulators, videos and scenarios investigated. Later the obtained results are discussed.
- Chapter 6: Concludes the current dissertation, suggests the expected future works and presents the published work associated with this project.

CHAPTER 2

Theoretical Reference

This Chapter presents some of the main concepts around VANETs, its characteristics and challenges of the technology. Quality of Experience is also discussed, as well as its evaluation metrics and how important an assessment is necessary in scenarios that involves multimedia content distribution. The AHP is explained in details, with a full explanation at a generic decision. After that, handover process is discussed, in terms of the taxonomy (types), aspects and challenges.

2.1 Vehicular Ad Hoc Networks - VANETs

Vehicles are becoming one of the main places that a human being expends time nowadays [9], due to the increase of car on the roads and consequently traffic jams. As a consequence, more vehicle companies are specializing in trying to offer great services for the vehicle users, such as better multimedia content, driving assistance, special information about the weather, etc. The vehicles are becoming smarter and more useful with multiple network aspects, and can be treated as VANETs.

VANETs are ad hoc networks that its main nodes are the vehicles. Each vehicle interacts with each other or with the infrastructure on the road/streets to create a viable network for some applications, such as content distribution. Due to ad hoc characteristics, VANETs allows a greater freedom for its nodes to self-manage and self-organize.

There are some common applications concerning VANETs. It can be used for safety, advertisement, among other applications:

- Safety: where the nodes can be used as a viable way to propagate an important message regarding human safety [10]. For example, if there is an accident on a highway, it is extremely important to propagate the message that there is an accident for the upcoming cars that are approaching the accident zone. Besides that, it is also important that the video/photo/message from the accident can be propagated for the emergency vehicle. By using this practice, there is a possibility for the paramedics and nurses to prepare themselves and the emergency first-aid procedures before reaching the accident zone [11]. Other types of problems can be weather/road conditions [12]. For example, a message about the weather (rain, hail, haze...) or the road condition (slippery, snow...) from a future point on the road can be used efficiently for the upcoming car's drivers to be mentally prepared before reaching the zone.

- ITS: Intelligent Transport Systems [13] are a big group of specific services that tries to manage vehicles in a smarter use of transport networks, such as traffic management, mobility and road transport. ITS services in VANETs can be used as a smart traffic light [14](that propagates messages to the vehicles containing information about where to drive to obtain low traffic volume), green wave [15](to make a series of traffic lights coordinated to allow continuous traffic flow for a special vehicle, *e.g.,* the ambulance) and other types of applications that takes benefits by using vehicles and transport infrastructure to propagate the information.

- Advertisement: the merchandising or ads propagation is the practice to contribute for a product sale, with the main objective to stimulate possible costumers. Ads messages' broadcast for vehicle passengers can be effective due to the long time that people spend inside the car, and can bring commercial profits to merchants [16].

- Infotainment: infotainment gives respect to multimedia content distribution. Video is the most consumed type of content today in computer networks [1], and people are consuming this content everywhere, whether on their smartphones, laptops, computers, or even cars. There is a big research toward video distribution involving vehicles [17, 18, 19], and such application is used in this dissertation.

Besides the applications, the vehicle networks can be organized among three distinct topologies: V2V, V2I and hybrid. The main difference between the three is the type of communication.

- Vehicle-to-Vehicle (V2V): is composed by an ad hoc of just vehicles, where each vehicle is equipped with an OBU (On-Board Unit) and can act as a sender/server or receiver/client. The V2V uses DSRC (Dedicated Short-Range Communication) or WAVE (Wireless Access in Vehicular Environments, IEEE 802.11p) as the main communication technology, which are technologies that enable a simple short-range communication between two nodes (vehicles). V2V has some challenges like short contact time between the nodes, high speed vehicles and other inherent problems. V2V is more appropriate for Safety applications (like the accident, weather and road condition messages).

- Vehicle-to-Infrastructure (V2I): Also called Infrastructure-to-Vehicle (I2V). V2I differentiates from V2V by using a fixed infrastructure, generally near the street/road. This infrastructure usually has a higher bandwidth, coverage area and computational power, quickly becoming a great manager to help the vehicles in some hard and specific applications, such as infotainment, ITS and merchandising. The infrastructure originally was planned to be a Roadside Unit (RSU), which is a computing device located on the roadside that could provide connectivity support to passing vehicles, however due to the monetary costs [20], this function was transferred for the radio base stations (BS). The main communication technology used in V2I is 3GPP Long Term Evolution (LTE) due to the base station presence.
- Hybrid: Also called Vehicle-to-Everything (V2X). This is the union from both the short-range communications of V2V and also the long-range communications from V2I. V2X usually happens when two or more applications are required at a vehicular network. V2X needs a higher coordination among its nodes and also is a more realistic scenario for dense urban settings.

In this master's dissertation it is used the V2I scenario with infotainment application (video consumption). The infrastructure used is formed by 3GPP LTE base stations that acts as servers for the vehicular nodes that acts as clients consuming the video. The transmitted videos are later assessed by a Quality of Experience performance metric to evaluate the effectiveness of the proposed handover algorithm.

2.2 Quality of Experience - QoE

QoE is a collection of performance metrics traditionally used to evaluate user's experience. Quality of Experience historically emerged from QoS and even though both seems similar, each one is used for distinct objectives nowadays. While QoS is more focused on the network quality aspects, *i.e.,* jitter, delay and packet delivery ratio, QoE is a more top-level assessment that tries to measure how the user, that will consume a product/service/content, reacts to it (positively or negatively).

In terms of video quality evaluation, Quality of Service (QoS) schemes alone are not enough to assess the quality level of multimedia applications, because they fail in capturing subjective aspects of video content related to human experience [7]. In this context, QoE metrics overcome those limitations.

2.2.1 QoE Performance Metrics

There are multiple ways to measure QoE indicators. Each one of these methods differentiate among themselves and has unique characteristics. Quality of Experience assessment can be mainly classified as Subjective, Objective and Hybrid. QoE can be used to evaluate anything: video, audio, phone call... given the necessary requirements. This dissertation focus on QoE Performance Metrics evaluating a video transmitted through a vehicular network.

2.2.1.1 Subjective Measurement

It occurs when a human evaluates a video/audio/multimedia content using his/her own perception by giving a score. Subjective Method is usually represented by the Mean Opinion Score (MOS), which is the most common QoE Performance Metric. MOS was originally developed by telecommunication enterprises to measure the satisfaction of the costumers at a phone call. Nevertheless, today it is used for any multimedia/service/product evaluation involving users/costumers.

Mean Opinion Score for a video can be executed in various manners. Usually a group of people (costumers and potential costumers) are invited to perform a series of videos evaluation. The test consist basically of the user watching two types of the same video: first, the original/uncompressed video, and later, the transmitted/compressed video. The user will answer about the quality from the second video, based upon the perception and differences he/she thinks that happened when changing between the videos. So using the first video as reference, the user will evaluate the transmitted video's quality according to a rating system ranging from number 5 (Excellent Quality) to number 1 (Bad Quality), where the bigger the number corresponds to a better video.

MOS	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Table 1: Mean Opinion Score: Scale

MOS Scale of values can be seen at Table 1 that relates the MOS value (quantitative result) with the Quality associated (qualitative perception) and the explanation in terms of Impairment associated to the video. After every user evaluates multiple videos, each one of these MOS values are associated in a simple arithmetic mean for this subjective quality evaluation test, as explained at Equation 2.1. MOS (and the other subjective measurements) major obstacle is associated with the difficulty in finding volunteers to participate for the MOS test.

$$MOS = \frac{\sum_{n=0}^{N} R_n}{N} \tag{2.1}$$

where:

R_n = individual ratings
N = number of subjects

2.2.1.2 Objective Measurement

QoE objective measurement is characterized by using mathematical equations to determine/estimate the QoE value of a service based on some specific parameters, *e.g.,* a difference in luminance from two videos. One advantage over the subjective counterpart is the shorter time to obtain the results of the assessed videos, and also the less dependency on costumers/volunteers (that are not required for a assessment phase), turning the objective method a good and low cost alternative. The main QoE objective performance metrics are: Peak Signal-to-Noise Ratio (PSNR)[21], Structural Similarity (SSIM)[22] and Video Quality Metric (VQM)[23].

Peak Signal-to-Noise ratio (PSNR) uses mean squared error (MSE) as the main mathematical formula to evaluate the video. It is basically a ratio between the maximum power of a signal and the power of corrupting noise: trying to measure the reconstruction quality of a frame/video based upon the original and the compressed content. However PSNR is not a really good performance metric due to instabilities on their results *i.e.,* not always the higher PSNR value results to a better video quality [24]. Due to this fact, it is appropriate to prioritize other more stable metrics.

SSIM $\in$ [0,1] is a measure that evaluates the structural, luminance, and contrast similarities between two images: original input (uncompressed) and output (compressed and transmitted). The analysis/comparison is made for all frames of the video. This method generally matches human visual perception, so if the SSIM results are good (higher values), the output image (and video) is also considered good.

VQM $\in$ [0,4] uses a Discrete Cosine Transform to measures the “perception damage” of video experienced based on features of the human visual system, namely blurring, noise, color distortion and distortion blocks. VQM values closer to zero means a video with a better quality. Both SSIM and VQM are great metrics for measuring objective QoE results. This dissertation uses MSU Video Quality Measurement Tool (MSU VQMT) [25] to measure the SSIM and VQM values for each transmitted video.

2.2.1.3 Hybrid Measurement

Hybrid Measurement is the most recent in terms of QoE assessment. It is not simply categorized, but generally uses some characteristics from both Objective and Subjective methods, taking the benefits from both methods. It predicts the perceived video quality level based on information such as frame loss and frame type, by applying a machine learning technique to correlate the video impairments with a predictive MOS score.

P.NAMS and P.BNAMS are both non-intrusive models specialized at IP-based video service assessment [26]. While P.NAMS provides audio, video and audiovisual quality estimation by considering packet-header information. P.NBAMS is also another non-intrusive model but only considers video assessment and uses further bitstream information such as coding-related information. In this master's dissertation, the hybrid QoE measurement was performed by predictive MOS (pMOS), developed by a former member of GERCOM lab[1]. pMOS is better explained at Chapter 4.

2.3 Analytic Hierarchy Process - AHP

AHP [8] is a decision making technique based on mathematics and psychology. It is used for many possible applications (business, industry, government...) and is usually chosen when there is a set of multiple (and often conflicting) criteria. AHP was created by Thomas L. Saaty, in the 1970s, and it was constantly being refined and updated.

AHP is used by decision makers when there is a need for a good decision without the dependency of subjective criteria, such as "I wish, I want, I guess". AHP can be applied for any decision, if it is structured the right way. AHP takes the problem and sums up in 3 initial steps: state the objective, define the criteria and pick the alternatives. The following hypothetical example [27] of buying a new car will be used for didactic approach for the AHP.

2.3.1 AHP Example Explained: Buying a new car

Suppose a man called Bob needs to buy a new car. However, Bob needs to evaluate what can be the best available car for him and his family. The car needs to be stylish (Bob likes the best looking car), reliable (to endure the the weekends trips) and be very effective in fuel economy (if possible). To help Bob in his task, he decides to use the Analytic Hierarchy Process.

First, he needs to perform the 3 initial steps. He starts by defining the objective: to buy a new car. Then, he defines the criteria to be evaluated: style, reliability and fuel economy. And finally, pick the alternatives available: Honda, Chevrolet, Renault and Ford. After that, the information is arranged in a hierarchical tree, as seen at Figure 1.

After declaring the objective, criteria and alternatives, Bob needs to ponder how each criterion relates to another. For solving this problem, AHP works by giving importance to a criterion over another, based on the decision maker's judgment. So Bob starts by relating what is the best criterion to select a new car. It is clear that if the car available is beautiful, super reliable and spends low fuel, it turns to be the best option. However an easy decision is not always available for Bob and every other decision maker nowadays, so AHP is an essential part in decision making.

Bob starts relating the three criterion, and this relation depends on a set of predefined values, called the Scale of Relative Importance, as depicted at Table 2, originally proposed by Saaty. The scale is a one-to-one mapping between a list of linguistic choices of the decision maker associated with numeric numbers. The numbers translate

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[1] http://www.gercom.ufpa.br/

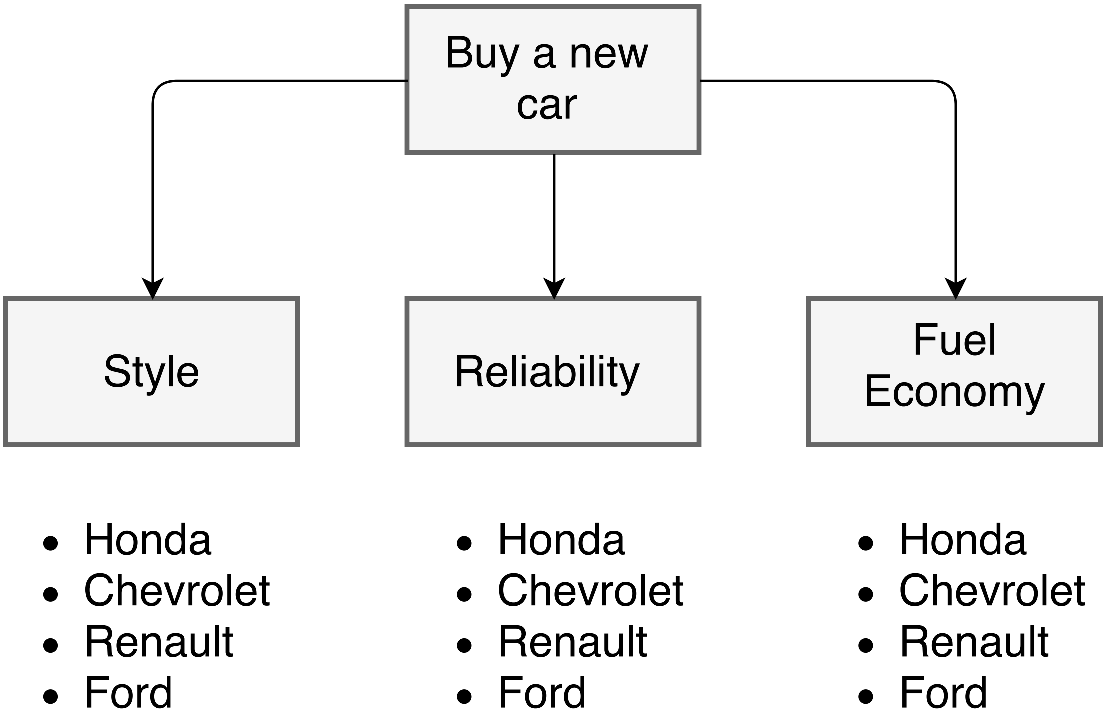


Figure 1: AHP hierarchy

as the weight/importance of each criterion in relation to another and are reunited as {1,2,3,4,5,6,7,8 and 9} for positive relation (more important than), and also as the inverse order {1/1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8 and 1/9} for negative relation (less important than). However, the Scale of Relative Importance of Table 2 employed in this example and at SER handover just used the range of 1 to 5 (positive relation) and 1/1 to 1/5 (negative relation) due to the few criteria evaluated.

Intensity of Importance	Definition
1	Equal Importance
2	Slight Importance
3	Moderate Importance
4	Moderate Plus Importance
5	Strong Importance

Table 2: Scale of Relative Importance for AHP

So *e.g.,* if the Style is 3 times more important than the Fuel economy when selecting a new car, this means that Bob moderately favors Style over Fuel Economy. The inverse relation is also valid: Fuel Economy is 1/3 more important than Style, which means that it is 3 times less important, which means that Bob moderately disfavors Fuel Economy over Style, when selecting a new car.

All these relations can be aggregated as the Judgment Matrix shown at Equation 2.2. Bob thinks that Reliability is the most important criterion, followed by Style, and then the Fuel Economy as the least important. Based on these judgments, the Judgment Matrix is formed when using the pairwise comparison. As stated before, after the relative importance is placed on the matrix, the inverse relationship is performed by using the inverse values, maintaining a consistency for the matrix. However Bob still needs to turn the Judgment Matrix into a ranking of criteria/priorities.

$$\begin{array}{c|ccc} & Style & Reliability & FuelEconomy \\ \hline Style & 1 & 1/2 & 3 \\ Reliability & 2 & 1 & 4 \\ FuelEconomy & 1/3 & 1/4 & 1 \end{array} \tag{2.2}$$

Saaty discovered that to turn and solve a pairwise matrix into a ranking of priorities (also known as Vector of Priorities) it needed to use eigenvector solution. Eigenvector is a special set of non-zero vector (often called characteristic vector) that can be used to represent a square matrix. One of the ways to solve the eigenvector is by applying a loop of multiplications: squaring the Judgment Matrix n times, summing the rows and normalizing, and checking if the difference between two consecutive calculations is smaller than a predefined value or if there is no difference.

The matrix used by Bob was approached as an eigenvector solution and iterated through the loop as shown at Equation 2.3. For this specific matrix, 6 iterations was enough, and the AHP solution can be seen at Equation 2.4 with the corresponding Vector of Priorities.

$$\left.\begin{array}{c} \text{Judgment Matrix X Judgment Matrix} = M_1 \\ \text{sum the rows for } M_1 \text{ and normalize to obtain Eigenvector 1} \\ M_1 X M_1 = M_2 \\ \text{sum the rows for } M_2 \text{ and normalize to obtain Eigenvector 2} \\ \text{Check if Eigenvector 2 = Eigenvector 1, if true (stops), if false continues} \\ \ldots \\ M_{(n-1)} X M_{(n-1)} = M_n \\ \text{sum the rows for } M_{n-1} \text{ and normalize to obtain Eigenvector n} \\ \text{Check if Eigenvector n = Eigenvector n-1, if true (stops), if false continues} \\ \text{Algorithm stops} \\ \text{Vector of Priorities = Eigenvector n} \end{array}\right\} \tag{2.3}$$

$$\text{Vector of Priorities} = \begin{array}{c} \\ Style \\ Reliability \\ FuelEconomy \end{array} \begin{array}{c} Priorities \\ \begin{bmatrix} 0.3196 \\ 0.5584 \\ 0.1220 \end{bmatrix} \end{array} \tag{2.4}$$

After the ranking of criteria, it is time to perform the same procedure for the alternatives when evaluated under each distinct criterion: each one of the four different options available (Honda, Chevrolet, Renault and Ford) are judged under the Style criterion (left side of Equation 2.5) and Reliability (left side of Equation 2.6).

$$\text{Style Matrix} = \begin{array}{c} \\ Honda \\ Chev \\ Renault \\ Ford \end{array} \begin{array}{c} \begin{array}{cccc} Honda & Chev & Renault & Ford \end{array} \\ \begin{bmatrix} 1 & 1/4 & 4 & 1/6 \\ 4 & 1 & 4 & 1/4 \\ 1/4 & 1/4 & 1 & 1/5 \\ 6 & 4 & 5 & 1 \end{bmatrix} \end{array} = \begin{array}{c} \\ Honda \\ Chev \\ Renault \\ Ford \end{array} \begin{array}{c} Priorities \\ \begin{bmatrix} 0.1160 \\ 0.2470 \\ 0.0600 \\ 0.5770 \end{bmatrix} \end{array} \tag{2.5}$$

The task consists in judging if in terms of style, Honda is more beautiful than the Chevrolet. If true, the relative importance is positive, otherwise is negative. When the judgment is made, it is time to use the same steps as performed by Equation 2.3: multiplying, summing the rows and checking the differences between two consecutive calculations. Computing the Eigenvector determines the relative ranking of alternatives under each criterion. The ranking of alternatives under each criteria are obtained at the right side of Equation 2.5 (for Style) and Equation 2.6 (for Reliability).

$$\text{Relia. Matrix} = \begin{array}{c} \\ Honda \\ Chev \\ Renault \\ Ford \end{array} \begin{array}{c} \begin{array}{cccc} Honda & Chev & Renault & Ford \end{array} \\ \begin{bmatrix} 1 & 2 & 5 & 1 \\ 1/2 & 1 & 3 & 2 \\ 1/5 & 1/3 & 1 & 1/4 \\ 1 & 1/2 & 4 & 1 \end{bmatrix} \end{array} = \begin{array}{c} \\ Honda \\ Chev \\ Renault \\ Ford \end{array} \begin{array}{c} Priorities \\ \begin{bmatrix} 0.3790 \\ 0.2900 \\ 0.0740 \\ 0.2570 \end{bmatrix} \end{array} \tag{2.6}$$

Bob has the Fuel Economy information available in terms of miles per gallons and decided to obtain the average economy calculus of all the alternatives to check what is the most economical car, as seen at Equation 2.7. Notice that the criteria (and AHP) can also be defined quantitatively, so a simple average is performed. Bob summed all the miles per gallons for each car and applied a normalization. And this normalization is the ranking of alternatives under Fuel Economy evaluation.

$$\text{Fuel Economy Matrix} = \begin{array}{c} Honda \\ Chevrolet \\ Renault \\ Ford \end{array} \begin{bmatrix} 34/113 \\ 27/113 \\ 24/113 \\ 28/113 \end{bmatrix} = \begin{array}{c} Honda \\ Chevrolet \\ Renault \\ Ford \end{array} \begin{bmatrix} 0.3010 \\ 0.2390 \\ 0.2120 \\ 0.2480 \end{bmatrix} \tag{2.7}$$

The qualitatively information (based on judgments) should only be performed when the quantitatively information is not available. To evaluate vehicles in terms of style is a hard process and it is based upon the decision maker's judgment. The same can be said when evaluating the cars in terms of reliability. The fuel economy information was the only criterion that Bob had numeric values, and due to that he used a simple average to obtain the ranking of alternatives.

Before going further, one important step to make is to check the consistency of the Judgment Matrix formed, by analyzing the Consistency Ratio (CR). Bob starts calculating the maximum eigenvector value, as seen at Equation 2.8: multiplying the sum of the columns from Judgment Matrix by the vector of priorities (principal eigenvector). Later he can obtain the Consistency Index (CI) as demonstrated at Equation 2.9.

$$\begin{aligned}\lambda_{max} &= [\text{Judgment Matrix' Sum of Columns}].[\text{Vector of Priorities}] \\ \lambda_{max} &= \begin{bmatrix} 3.33 & 1.75 & 8 \end{bmatrix} . \begin{bmatrix} 0.3196 \\ 0.5584 \\ 0.1220 \end{bmatrix} = 3.0174\end{aligned} \tag{2.8}$$

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{3.0174 - 3}{3-1} = 0.0087 \tag{2.9}$$

where:

λ_{max} = Maximum Eigenvector Value
n = Number of Criteria
CI = Consistency Index

Next, the Consistency Ratio is obtained by diving by a certain number from Table 3 called the Ratio Consistency Index (RCI). If the CR is lower than 0.10%, the judgment matrix is considered adequately consistent and it is appropriate to be used. However if it does not respect this Equation 2.10, it is better to study the problem further and recheck the relation between criteria. The CR calculation for Bob's problem was 1.5%, meaning that the AHP is correct.

$$CR = \frac{CI}{RCI} = \frac{0.0087}{0.58} = 0.015, \text{ where } \begin{cases} CR < 10\% \rightarrow \text{ adequate} \\ CR \geq 10\% \rightarrow \text{inadequate} \end{cases} \tag{2.10}$$

where:

RCI = Ratio Consistency Index
CR = Consistency Ratio

For the last part of AHP calculation, it needs the Vector of Priorities multiplied by the ranking of alternatives under each criterion, as seen at Equation 2.11. The ranking of alternatives are aggregated into a single matrix. After the multiplication, as seen at Equation 2.12, Bob can notice that the Ford alternative has the highest value (AHP score),

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Table 3: Redundancy Consistency Index (RCI)

which means that it is the most adequate car to buy following the priorities (Reliability > Style > Fuel Economy) defined by him. AHP can be considered as a logical framework for decision analysis, where it can shows the benefits of each alternative based on a set of criteria for a given problem.

$$\begin{array}{lc} & \begin{array}{ccc} Style & Reliability & FuelEconomy \end{array} \\ \begin{array}{l} Honda \\ Chevrolet \\ Renault \\ Ford \end{array} & \left[\begin{array}{ccc} 0.1160 & 0.3790 & 0.3010 \\ 0.2470 & 0.2900 & 0.2390 \\ 0.060 & 0.0740 & 0.2120 \\ 0.5770 & 0.2570 & 0.2480 \end{array}\right] \end{array} . \begin{array}{lc} & Priorities \\ \begin{array}{l} Style \\ Reliab. \\ FuelEcon. \end{array} & \left[\begin{array}{c} 0.3196 \\ 0.5584 \\ 0.1220 \end{array}\right] \end{array} \tag{2.11}$$

$$\begin{array}{lc} & Criteria \\ \begin{array}{l} Honda \\ Chevrolet \\ Renault \\ Ford \end{array} & \left(\begin{array}{c} 0.3060 \\ 0.2720 \\ 0.0940 \\ 0.3280 \end{array}\right) \end{array} \tag{2.12}$$

2.4 Handover

Handover process occurs when there is a transfer from an ongoing data session of a device from a base station to another. Originally handover was just associated for transferring an ongoing telephone call between two cell stations, however the definition became broader nowadays with the advance of telecommunication systems, enabling a handover of ongoing data session, *e.g.,* of an Internet access.

Handover and handoff are the same process, however handover is the term used in Europe by the telecommunication operators and associations, such as 3GPP, which is responsible for 3G, LTE and 5G. In America the mostly used term is handoff. A classic handover is depicted at Figure 2: when the signal strength is low, it performs handover to a stronger signal cell.

There are some common requisites for the handover. **i)** it is essential nowadays. **ii)** it must be transparent. **iii)** it needs to be efficient or without problems. The three requisites are explained as follows.

i) As stated, handover is an essential part of networks. The cities are populated by several 3GPP LTE base stations that cover a big area, depending on the antenna's size.

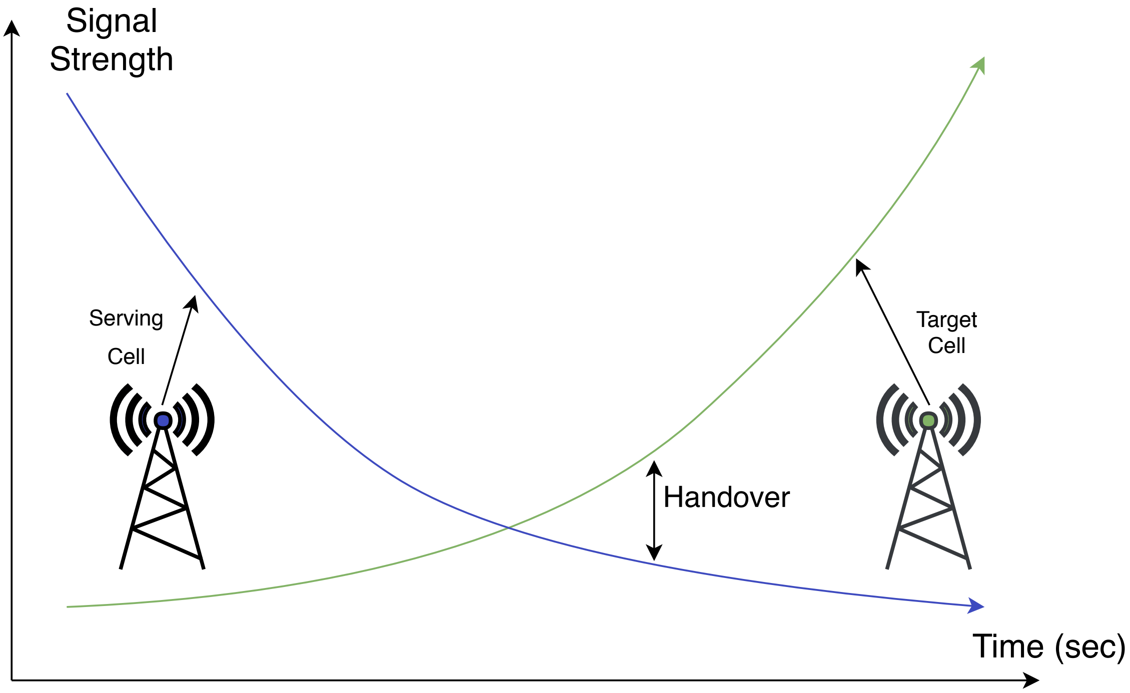


Figure 2: Classic Handover

The antenna's size categorize the different Base Stations according to the coverage area: macro, small, pico, femto... each one with its own transmission power and consequently distinct coverage areas.

However, at a big city, there must be more than one base station to support the multiples numbers of users. And each one of these base stations are usually displayed in a way to reach every area, shrinking the possibility of coverage holes. For the good working of this system, when someone is connected to a base station and starts to move towards the edge, it will eventually leave the area from the original serving cell and will need to traverse to other candidate base station. The handover will generally occur in a situation like this.

ii) The handover needs to be transparent, which occurs when a user notices no discernible disruption while using his Internet connection or when is at a telephone call. If the handover occurs and the user does not experience any drop in Quality of Service or Experience, it is considered a transparent handover. A transparent handover is the ideal handover in any situation. The disruption and drop of quality of experience acts as a key performance indicator for a mobile operator: the users usually evaluate the service provided in the act of a handover.

iii) Efficient handover is generally associated with a good decision. If the handover occurs from one cell to another and the User Equipment (UE) continues to experience a good quality, and does not need to change the cell again a little time later, it is considered an efficient handover, at least in terms of costs. Handover inflicts high signaling load at wireless medium and should be used only when it is essential: if there are two great options available (the serving cell and the target cell) with the same quality offered, it is better for the UE to stay connected at the serving cell to avoid waste of resources.

2.4.1 Handover Manager and Classic Handover Phases

The execution of a handover (HO) is traditionally done in three steps, as illustrated in Figure 3: HO Measurement phase, HO Decision and HO Execution. The responsible for the handover process is called Handover Manager, which will store and execute the handover algorithm. The Manager is the logical entity responsible for all the phases involved. However it naturally assumes other names when applied in different technologies, *e.g.,* in LTE the Handover Manager function is performed by MME (Mobility Management Entity) and SGW (Serving Gateway), but in this work it is used the broad term for simplification.

Figure 3: Handover Classic Phases

- Measurement: where the algorithm collects some important information to be used for the handover decision. It is important that these parameters be the fastest and most resourceful collected information for the handover manager to take the decision. The information collected depends upon the handover algorithm: *e.g.,* signal strength values, QoS-information, etc. A bad measurement phase occurs when the manager cannot take the appropriated information from the other cells.
- Decision: This is the most important phase of all the handover process. A good decision can result to a good QoS and QoE output for the consuming users. However, a bad decision can give terrible results. The manager will access the available information from the distinct cells available and will decide if a user equipment changes or if it keeps at the same cell. Note that the decision to stay at the serving cell is also a valid decision. A bad decision occurs when the manager chooses a not appropriate cell to handover or to stay. The wrong decision and other HO problems are better explained at Subsection 2.4.4.
- Execution: after the measurement and decision taken, it is time for the execution of the process. This is the phase perceived by some users if the handover is not transparent, *e.g.,* a decrease in the overall quality of a consumed content such as a video. A bad execution occurs when the handover takes too long to execute or when it is not possible to be performed.

2.4.2 Handover Cell terms

There are some common terms at the handover process that needs some briefing.

- Serving Cell: The serving cell is the current base station that the user equipment is connected. The handover process generally starts due to a decrease in the content offered by the serving cell, or after a decrease in signal quality for classic HO algorithms.

- Candidate Cells: The candidate cells are all the available base stations that are fit to receive the handover of a device. The candidates are usually within reach of the user equipment. At the moment of decision, the handover algorithm will evaluate "What is the best cell to connect?", and compares the serving cell against the candidate cells. If there is not a better cell available, the handover decision will be to stay connected at the serving cell. However, if there is a better cell available, the algorithm will choose the best cell available to receive the handover.

- Target Cell: is the denomination for the best cell available chosen by the handover algorithm to receive the UE after the execution of handover.

2.4.3 Types of handover

Traditionally handover are categorized as horizontal, vertical and diagonal handover by the industry and research community, as shown at Figure 4.

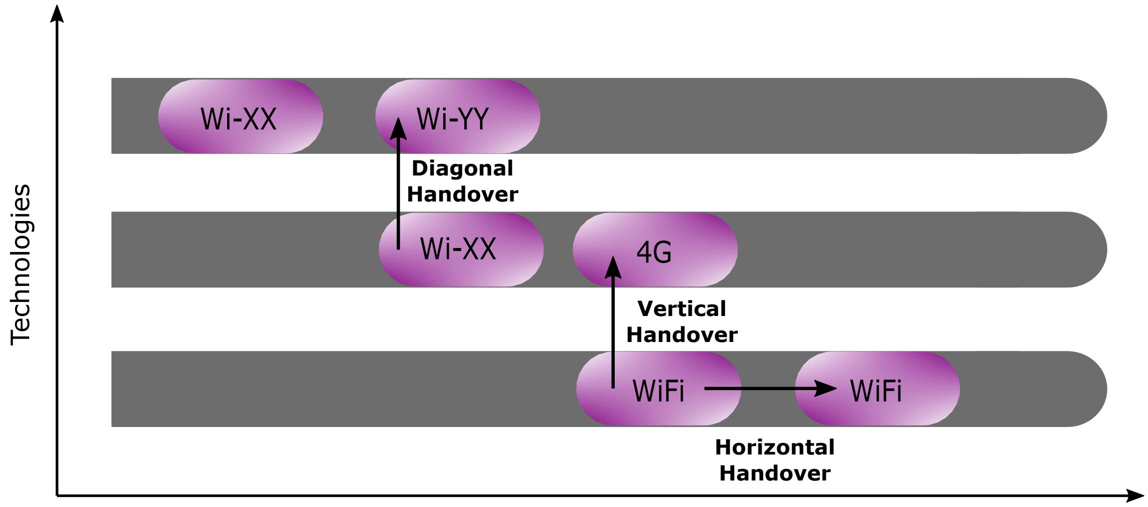


Figure 4: Types of Handover

- Horizontal Handover: is characterized as a handover when there is a intra-cell or intra-domain change. The connected user equipment changes between two cells that use the same technology while keeping their original IP address assigned. It can also be referenced as a soft handover, although it does not have the exact same meaning.

- Vertical Handover: is characterized by a deeper process involving the handover when there is a inter-cell, inter-domain, inter-RAT (Radio Access Technology) change. The connected user equipment change its access point to another that uses a different technology, for example: handover from a LTE base station to Wi-Fi AP (access point). Due to such a harsh process, it is also referenced as a hard handover because there is a change of network interfaces and terminal connections, although the terms do not necessarily have the same meaning.

- Diagonal Handover: It is the combination of horizontal and vertical handover. The user equipment changes its route and underlying technology connected simultaneously (*e.g.,* Ethernet). In IEEE 802.21 group, this is the proposed term for handover, and can also be referenced as Media Independent Handover (MIH) [28].

The handover can also be characterized as Hard or Soft:

- Hard Handover: Occurs when the source channel is released for the UE, and then the new channel with the target cell is established. It is also known as break-before-make handover.
- Soft Handover: Occurs when the channel from the serving cell (which the UE is attached) is retained in parallel with the new channel from the target cell (which the UE will perform handover to) for a brief period of time before the old connection is broken. It is also known as make-before-break handover.

2.4.4 Handover problems

Handover is a critical process in telecommunications systems and is not always a simple task for the base stations/point of access to execute it flawlessly. Due to this critical situation, here it is presented the main problems regarding handover that are worth noting. Figure 5 and Figure 6 summarizes the handover problems.

- Too early handover: When the handover execution performs the handover before the proper time and the UE does not succeed to connect to the chosen cell.
- Too late handover: It occurs when the handover takes a long time to execute resulting at a radio link failure. The speed of the user equipment can favor this type of problem, especially if the UE is a high speed vehicle.
- Wrong cell handover: A bad handover occurs when the handover decision does not select the most suitable target cell. As a consequence, there is a degradation in the content delivered after the execution of this wrong cell handover.
- Ping-Pong Handover: It happens when the handover manager performs a handover to a cell but a few moments later (4-6 seconds) the device returns to the previously connected cell (performing a second handover). Handovers are very costly to the networks and its classic phases should be carefully performed. Every handover generates a high signaling load to the telecommunication infrastructure and the repetition of this act, of back and forth, is harmful for any application.

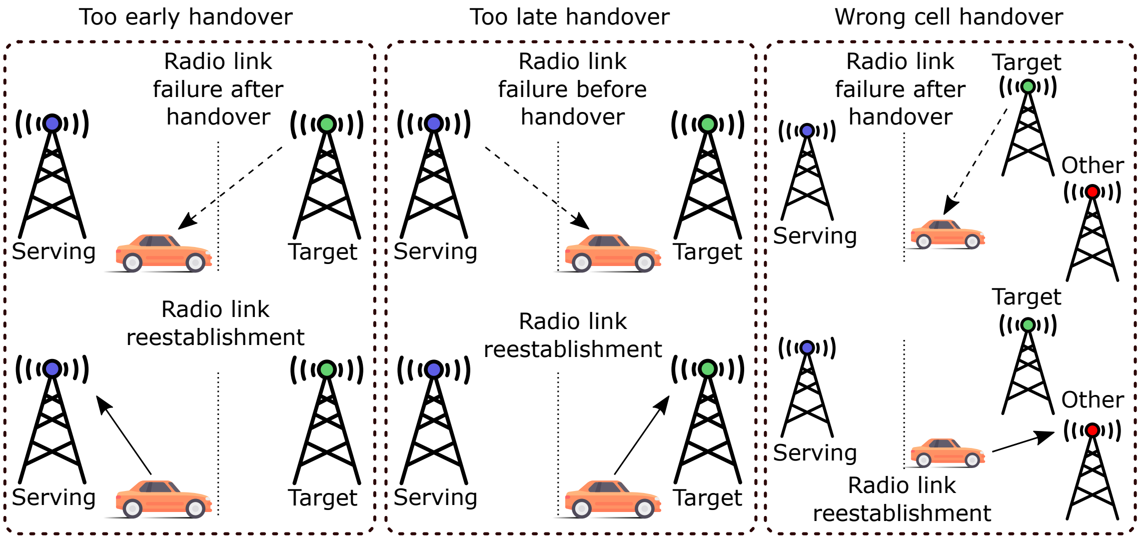


Figure 5: Handover Problems

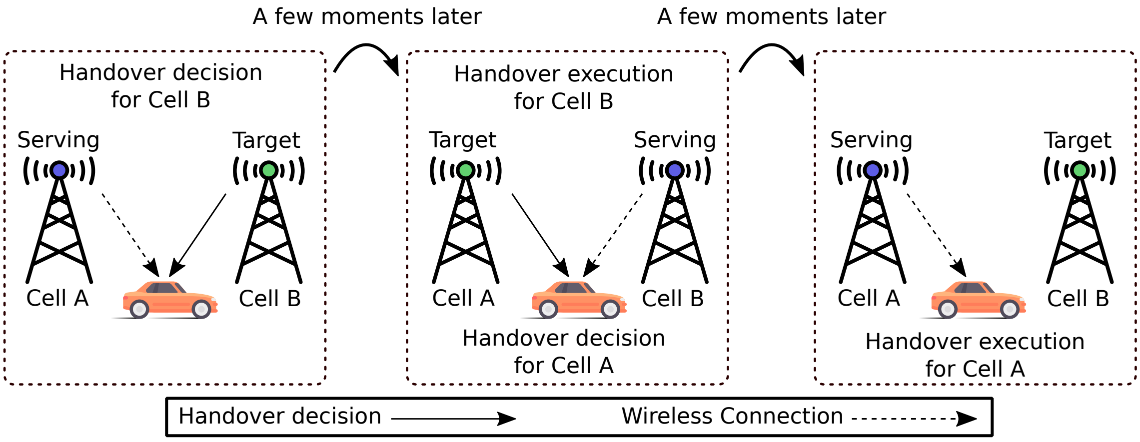


Figure 6: Ping-Pong Handover

2.5 Handover algorithms

Handover algorithms as a general rule try to follow the concept of Always Best Connected (ABC) [29], which states that all the user equipment must be connected every moment at the best possible cell. Due to this, many algorithms were proposed over the years. According to Ahmed *et al.* [6], the algorithms are categorized according to the main parameter that is responsible for triggering the cell selection at handover decision phase, and are here presented at five main groups: Received Signal Strength-based schemes, QoS-based schemes, Decision function-based schemes, Network intelligence-based schemes and Context-based schemes.

- RSS-based: one of the most common and classic types of handover schemes is the signal strength based algorithms, as referenced by Chang *et al.* [30]. The algorithm works by scanning the available networks, obtaining the Received Signal Strength (RSS) from the candidate cells, comparing with the serving cell RSS value and performing handover if there is a better cell in terms of signal strength value. While effective at homogeneous networks that required a simple horizontal handover, this single parameter strategy does not fulfill the requirements for a good handover nowadays, especially if there are mobile users involved and if the networks is heterogeneous. However, RSS can still be used in association with other QoS-based parameters. In this dissertation, one RSS-based algorithm is evaluated against our proposal in Chapter 5.

- QoS-based: the algorithms are categorized by QoS-aware alternatives that focus on trying to provide a steady or a better provision in terms of Quality of Service for the users by using some parameters such as available bandwidth, user preferences, jitter, delay, as described by Lee *et al.* [31]. The algorithm follows a similar flow such as RSS-based, but the decision compares other types of parameters, like the already mentioned bandwidth and delay. If the candidate cell has better results in terms of QoS-related values, it becomes a target cell and receives the UE. While QoS is better than RSS-based at heterogeneous scenarios, it still has some limitations and it is more appropriate for user satisfaction and non-real time applications. More criteria are needed for a more suitable decision for applications that demand real time and are delay sensitive. In this dissertation, one QoS-based algorithm (PBGT) is evaluated against our proposal in Chapter 5.

- Decision function-based: the scheme uses a set of criteria to estimate the most suitable cell for handover, as shown by Wu *et al.* [32]. The handover manager collects the available network cell status (usually more than one criterion), evaluates at a mathematical model (generally a weighted sum) and compares if this calculated value is higher than the current of the serving cell. If there are better options available, it performs handover. However if there are no better options in terms of the calculated value, the UE stays connected at the original serving cell. While the decision function is interesting, it just make assumptions based on the current system (network) state.

- Network intelligence-based: In order to tackle real time applications, it is important to have a good predictor that can estimate when to execute a handover based on previous patterns. The intelligence-based algorithms (fuzzy [33], artificial neural networks [34] or intelligent protocol-based [35]) try to correlate when, where and over which cell to choose among the available ones, as explained by Hussein *et al.* [36]. While this type of algorithms are very powerful, it cannot be denied the high time spending for obtaining and training the dataset and also the high delay at the decision in some cases.

- Context-based schemes: context is defined as any information that is pertinent to the situation (handover) of an entity (handover manager). The context needs to be constantly detected, collected, stored, updated and distributed to the handover manager to enable a good decision, due to the complex scenario of nomadic users and heterogeneous base stations. One of the examples regarding context type is the Analytic Hierarchy Process and is characterized as multiple context collection to be used by the handover manager. AHP can be resource consuming and might compromise if a low cost network is available, but the SER handover presented in this dissertation (that uses AHP calculation) is ideal by tracking few and distinct criteria (context) and uses a strategy to eliminate the low cost bug problem (better explained at the Algorithm in Chapter 4).

2.6 Chapter Conclusions

This Chapter provided a good insight about the theme of Vehicular Ad Hoc Networks, Quality of Experience assessment, Analytic Hierarchy Process and detailed several important characteristics regarding Handover. All these topics presented in this Chapter serves as a basis for a better understanding of this dissertation. Now it is time to move towards the related work from the literature.

CHAPTER 3

Related Works

In this chapter it is presented the main related works surrounding handover solutions for heterogeneous and vehicular networks. Also, after presenting the main types of handover schemes at Chapter 2, it is appropriate to explain in more details the handover algorithms used in this dissertation (RSSI-Based and PBGT) that are compared against the proposal (SER).

3.1 Related Works

The research on efficient handover algorithms in mobile networks are essential to provide adequate performance in delivering content to mobile users. However, designing such algorithms is not a simple task due to the diversity of networks and the requirements of the requested services, such as low packet loss rate and delay. Over the last few years, solutions have been proposed, such as the Media Independent Handover (MIH) [28], which proposed to standardize the different technologies related to the IEEE 802.21 standard under one single interface.

Algorithms purely based on signal strength [37] (*e.g.,* RSSI-Based and strength-based) were initially designed and implemented on a large scale, and can be categorized as a RSS-based scheme. RSSI-Based has many names in literature and is referenced in this dissertation simply as classic handover algorithm or strength-based algorithm or A2-A4-RSRP algorithm.

According to 3GPP [38], for this algorithm, there are two events to trigger the handover decision. It starts when the signal strength of the current serving cell is worse than a certain threshold (Event A2) and when the signal strength from the neighbor cell value is better than this same threshold (Event A4). By default, the threshold is a very low value for the algorithm to always pass this criterion enabling the execution of handover. However, these algorithms demonstrated to be inefficient in heterogeneous scenarios [39].

With the increase in heterogeneity and consequently network complexity, it was necessary to design new algorithms for the handover [6] process. In this way, the handover algorithms underwent a process of evolution, considering different parameters and techniques. One of the alternatives was the algorithms based on QoS [40, 41], which use parameters related to network services, such as channel bandwidth, flow, delay and jitter.

The Traditional Power Budget Algorithm (PBGT) was developed by Dimei et al. [41] and acts as a QoS-based scheme because it takes some information to complement the signal strength value at the handover decision. PBGT can also be called Strongest Cell Handover algorithm or A3-RSRQ algorithm.

The handover is activated when it detects a bigger signal strength value at the neighboring cells compared to serving cell (Event A3, defined by 3GPP [38]). In addition to that, the algorithm uses two extra parameters (hysteresis and time-to-trigger) to add delay to the handover decision.

The first parameter is hysteresis (also known as handover margin) that delays the handover in regard of signal strength. The other parameter used is time-to-trigger (also known as handover waiting time) that delays the handover in regard of time. Both parameters [38] were added to limit the handover frequency and to tackle the ping-pong problem.

The PGBT algorithm works as follows: it starts by detecting a better signal strength at the neighbors (Event A3); if the neighbor cell and serving cell signal difference is greater than a hysteresis; it waits a certain time-to-trigger; the handover is executed just after the time-to-trigger is completed and it must execute all the tree steps.

Other algorithms and works were also proposed and influenced this work. Elhadj et al. [42] focus on the decision schemes and investigate the Multi-Criteria Decision Making (MDCM) methods at a wireless body area network. The authors propose a Multi-Criteria Decision Making Handover Algorithm which helps patient's mobile terminal to dynamically select the best network by providing a ranking order between the list of available candidates.

Elhadj et al. use QoS-based parameters and try to improve the overall efficiency of their proposed handover when compared with strength-based algorithm (such as A2A4). It also attempts to tackle some other questions such as ping-pong handover. However such work does not address issues such as users' QoE and it does not apply to mobile networks.

Drissi et al. [40] try to provide users with the appropriate QoS in terms of operator's and user's preferences by presenting three mathematical models of different vertical handover decision algorithms: called SAW, TOPSIS and MEW in four different types of applications.

Drissi et al. use the following QoS parameters: bit error rate, jitter, delay and throughput. The three mathematical models are used in association with AHP and try to decide the best combination alternative. It is simulated in a Wimax and WLAN environment. However this work was not evaluated in a vehicular network environment, where there can be presence of high speed vehicles that can increases handover latency and ping-pong effect.

Hussein et al. [36] propose a MCDM method. In this method, they use an integrated fuzzy technique for order preference in association to TOPSIS to answer the handover decision and affirms that the conventional cell selection in LTE is based on signal strength criterion, but it is inadequate to uniquely rely upon it.

The fuzzy TOPSIS technique of Hussein et al. [36] use certain parameters more associated with radio aspects: like Signal strength, criterion, availability of LTE resource blocks and uplink signal-to-interference-plus-noise ratio (SINR). It also tries to tackle ping-pong handover.

Xenakis et al. [43] highlight the key aspects of the cell HO process in the presence of small cells and identify the main issues that affect its robustness. The authors summarize lessons learned from literature on HO decision algorithms for small cells, and present an algorithm for alleviating interference in the cellular uplink while prolonging the battery lifetime of the user terminal.

Xenakis et al. show a different HO classification than the used in this dissertation (*e.g.,* speed-based and energy-based schemes), give details about the great importance of small cells at heterogeneous networks (that inspired SER algorithm in trying to prioritize smaller/idle cells), however it does not explain how to define the weights.

Chaudhuri et al. [44] propose a novel and efficient self-optimizing handover detection along with HO execution and decision parameter optimization algorithm which is named as Handover Detection Self-Organizing-HO Parameters based on Reinforcement Learning concept. The authors affirm that while 3GPP introduced the concept of Self Organizing Networks at LTE-A, it is still not efficient due to high-speed mobility requirements and the ever growing complexity of the networks. The authors present a simple algorithm for LTE-A, controlling Time-To-Trigger and Hysteresis to try to reduce HO ping-pong and failure.

Mansouri et al. [45] declare that the integration of different networks results in performance degradation when handovers occur during a mobility event. As a result, the effective mobility management protocols are required to support ubiquitous network access by providing seamless handover.

Mansouri et al. driven by the need to provide the subscribers seamless services across heterogeneous networks, try to design effective horizontal and vertical HO modules by implementing different MAC layer levels integrated with MIH framework. The authors use the available bandwidth, velocity of the mobile, delay, SINR and the channel quality as parameters and attempt to estimate which is the most appropriate BS based on the data rate estimation.

La-Roque et al. [39] affirm that the cell selection and handover procedures found in LTE Release 8 are inefficient in heterogeneous scenarios, since they are based only on signal strength for cell selection and handover. The authors implemented two additional criteria as an improvement for the cell selection and handover procedures: base station capacity estimation and user speed.

La-Roque et al. tries to evaluate the proposal in a heterogeneous vehicular scenario and classifies the vehicles according to speed (which inspired the nodes definitions in this dissertation). However the authors do not take into account aspects such as QoE or video dissemination.

3.2 Chapter Conclusions

Based on the analysis of the related works, it is clear the need for more study surrounding handover at vehicular scenarios, especially when dealing with high-speed nodes. The approach for using AHP as a MCDM technique was referenced by Ahmed et al. [6] that praised its use to achieve a better and smarter decision.

Chandavarkar et al. [46] also produced a study considering the most famous techniques to answer a MCDM, and praises the AHP for having a good performance for applications that demand high bandwidth and low delay, in which this dissertation fits. The weak point of AHP, according to Chandavarkar et al. [46], takes place when it has many parameters in its decision, so here it is used just a few and very distinct attributes, chosen and considered essential to achieve a good answer and consequently a good decision. In addition to simple parameters, we judged that the use of a QoE-aware algorithm in addition to QoS-aware and signal strength parameters in a vehicular environment could be interesting and could deliver a good result at video dissemination. Table 4 classifies the related works based on handover decision that inspired this work.

Proposal	QoS	QoE	Network	Technique	Objectives
IEEE[28]	no	no	Mobile	MIH	Padronization
3GPP[37]	no	no	Mobile	RSSI-Based	Padronization
Dimou et al.[41]	yes	no	Mobile	PBGT	Better efficiency
Elhadj et al.[42]	yes	no	W.BodyArea	MCDM	Better efficiency
Drissi et al.[40]	yes	no	Mobile	AHP	Reduce delay/pack.loss
Hussein et al.[36]	no	no	Mobile	Fuzzy Topsis	Reduce Ping-Pong
Xenakis et al.[43]	yes	no	Mobile	QoS-Based	Reduce interf./energy
Chaudhuri et al.[44]	yes	no	Mobile	SO-HO	Reduce Ping-Pong/loss
Mansouri et al.[45]	yes	no	Mobile	Modified MIH	Better efficiency
La-Roque et al.[39]	yes	no	Vehicular	QoS-Based	Better load balancing
Current proposal	yes	yes	Vehicular	yes	Better efficiency

Table 4: Related Works

CHAPTER 4

SER Handover Algorithm

In this chapter the SER Handover Algorithm is presented in details. It is explained the main handover process, algorithm flow and how the handover manager operates. The AHP calculation, as explained for the generic example of Chapter 2, is utilized here for the main handover decision problem: "Is there a better cell to connect?". For the rest of this chapter: Handover is also referenced as HO, User Equipment are called UE, nodes, vehicles or devices, and base stations are BS, infrastructure, cell or antenna.

4.1 SER Handover - Overview

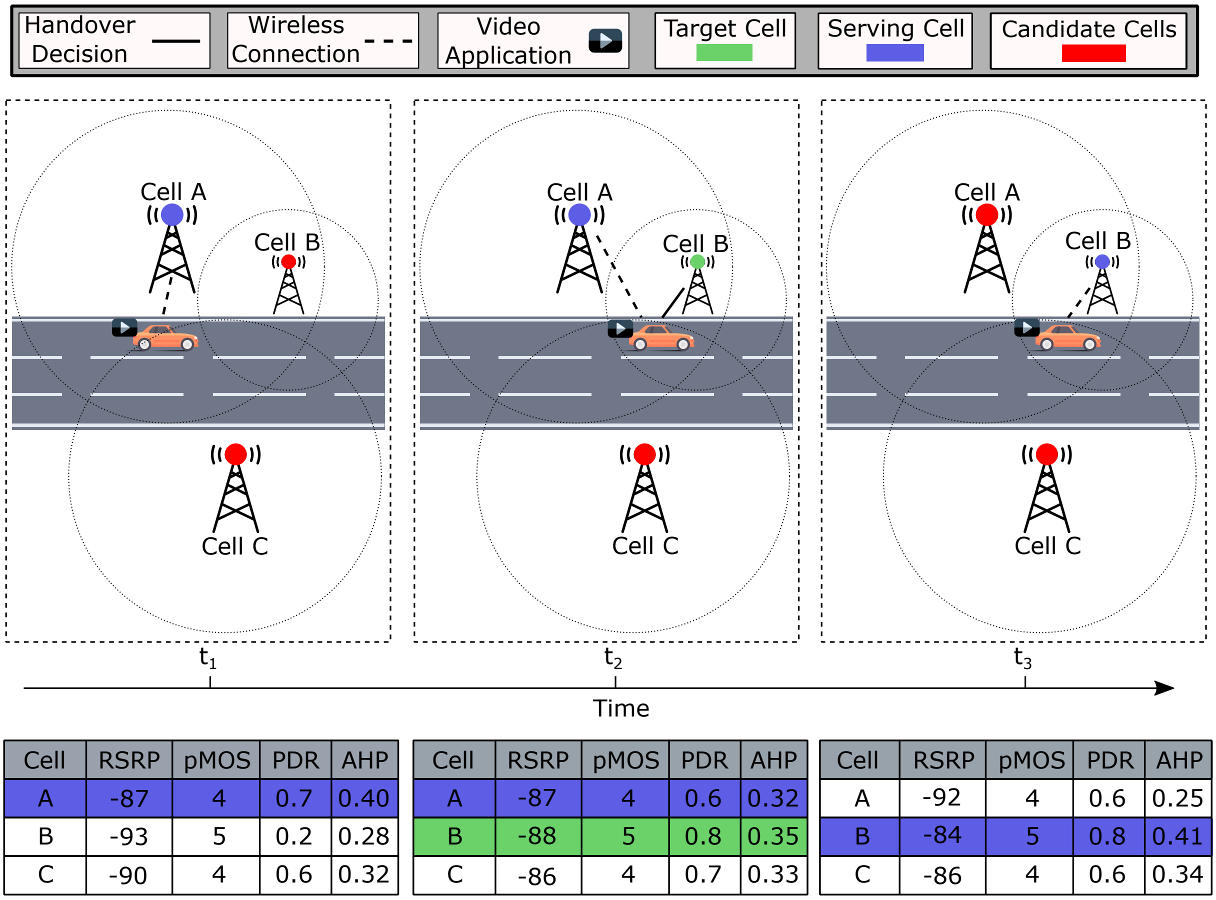
Figure 7 is an overview representation for the SER handover. There are three times chronologically represented at the image (t_1, t_2 and t_3) for the same infrastructure (of macrocell A,C and small cell B). The figure depicts just one UE (vehicle) moving from left to right. It is important to notice that there are other connected UEs at the three cells depicted, however they are not represented to facilitate the understanding of the image.

At the bottom part of the image there are three small tables that depicts the three cells status evaluated by AHP calculation at the three different times (t_1, t_2 and t_3). The table has the following information for the three cells (A, B and C) available: RSRP value ($\in$ [-100,-80]), pMOS value ($\in$ [0,5]), PDR value ($\in$ [0,1]) and resulting AHP score ($\in$ [0,1]). For all these parameters follow the rule of higher is better. The RSRP is reported by UE, while pMOS and PDR is reported by BS. The AHP score is calculated by using the RSRP, pMOS and PDR.

At t_1, the vehicle is connected to macrocell A and it is using a video application. At t_1, the macrocell A is the serving cell for the UE, while the others cells (B and C) are just candidate cells. The left side table can testify the status and the corresponding AHP scores calculated for the three cells.

At t_2, the vehicle moves a little further and it keeps connected at the serving cell A. However, the status for all three cells (A,B and C) changed a bit. The AHP score is calculated for the three base stations and discovers that the cell B is the best cell available (turning it into a target cell). Now the HO algorithm has the following decision: to execute handover of the connected vehicle from macrocell A to small cell B. From the transition of t_2 to t_3, the handover is performed, and the UE that is now connected at the small cell B. So the new serving cell is the base station B.

Finally, at t_3, the AHP values is again calculated and the serving cell B continues with the highest AHP score: so the HO decision phase orders for the UE to stay at the current cell. This overview figure is a good representation for the SER handover behavior's explanation.



Cell	RSRP	pMOS	PDR	AHP
A	-87	4	0.7	0.40
B	-93	5	0.2	0.28
C	-90	4	0.6	0.32

Cell	RSRP	pMOS	PDR	AHP
A	-87	4	0.6	0.32
B	-88	5	0.8	0.35
C	-86	4	0.7	0.33

Cell	RSRP	pMOS	PDR	AHP
A	-92	4	0.6	0.25
B	-84	5	0.8	0.41
C	-86	4	0.6	0.34

Figure 7: SER Handover Overview

4.2 SER - Handover Manager

The execution of a handover is traditionally done in three phases: **i)** information measurement; **(ii)** handover decision; and **iii)** execution of the handover, as explained at Figure 4 from Chapter 2. All these three actions are performed by the HO Manager, which is a key entity in terms of handover process.

Some of the functions performed by the HO Manager can be seen at Figure 8. The Handover Manager controls the infrastructure (macrocell, smallcell...) and access its internals components like the mobility manager (which tracks where the subscribers/consumers are), the handover algorithms (that stores the main algorithms about handover) and the video server (which is the database for the videos consumed by the UEs). There are other functions performed by the HO Manager but were not represented.

The video content is asked by the UE to the BS, but the HO Manager is the responsible to answer the incoming requests, accessing the video server database and sending the video through the connected BS that the UE is currently connected. The data flows from video server up to the connected node.

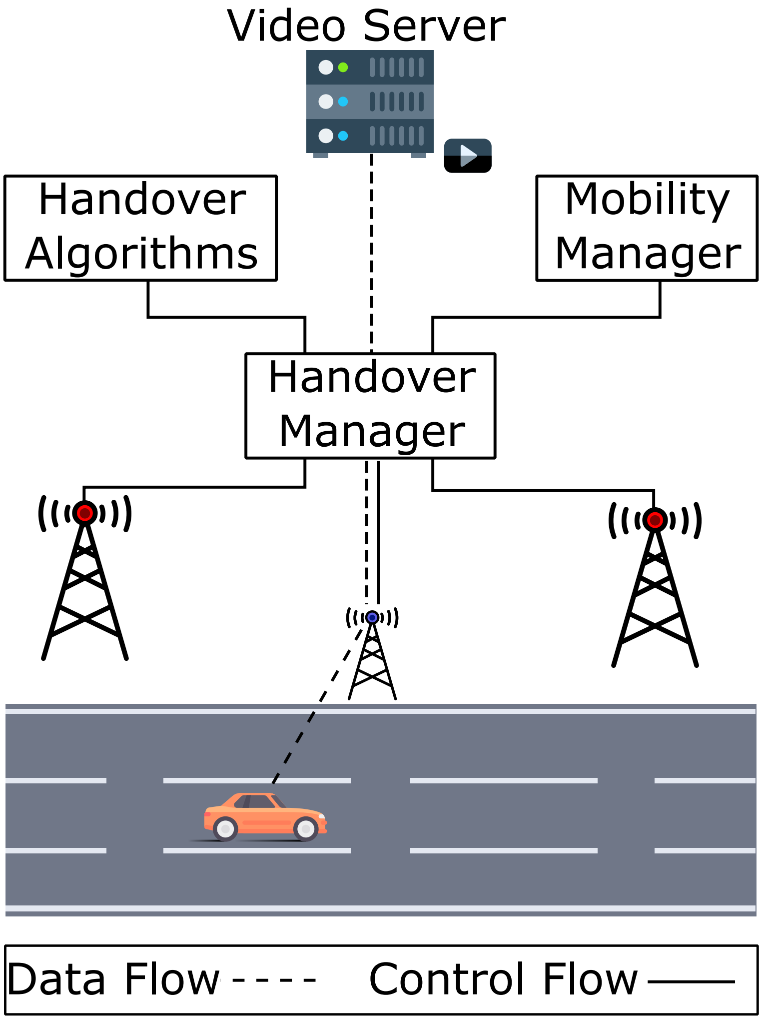


Figure 8: AHP HO Manager

4.3 SER - Handover Algorithm

Algorithm 1 represents the operation of the proposed SER handover. At the beginning of the simulation, for all User Equipment (UEs) and Base Stations (BSs), after the BS activates the HO Manager, the UE connect to their closest BS at range and requests video content (lines 1-5 in Algorithm 1).

While the UE is connected, HO Manager assumes the handover classic phases. It starts with the HO Manager requesting the measurement reports recorded by the UEs and the BSs (lines 6-7 in Algorithm 1), at the Measurement Phase.

The information required at the measurement report are the three parameters (RSRP, PDR and pMOS) and also the ID of the UE/BS (that can be a number or the network IP). The Manager receives the beacon from UE: that reports all the available BS RSRP at range for that UE (line 8 in Algorithm 1). The RSRP value is specific for each UE and due to this, it needs to be reported by each UE to the HO Manager. In other words, the report of signal strength of one node is not valid to other node.

With the information about the RSRP and ID of the available BSs, the Manager will access the already mentioned BSs and collect the average PDR and pMOS values from the candidate cells and the current PDR and pMOS value from the serving cell (line 9 in Algorithm 1). From the serving cell it is used the current values that the UE is currently experiencing. However, from the other base stations, the pMOS and PDR is used based on a exponential moving average of all the connections of that cell.

If there is no connected UE to a BS, the HO Manager categorizes the idle BS as a cell with high PDR and pMOS values. This strategy is used for the UE to give preference to idle cells and to adjust the load balance across all the available cells (thus decreasing the high load on the popular BS)

After receiving the reports collected (Measurement Phase), HO Manager will then trigger the AHP that will use this data for the upcoming handover decision (line 10 of Algorithm 1). For each detected BS, the AHP calculates the score of each cell detected by the node (lines 11-13 of Algorithm 1) and detects the Best Cell ID as the highest score BS option (line 14 of Algorithm 1) concluding the Decision Phase.

If the highest AHP score is from the serving cell, there's no action to be taken (the UE is currently at the best available BS). However if the best cell is not the serving cell that the UE is currently attached, the HO Manager will execute the handover to the best cell, also known as Target Cell (lines 15-17 of Algorithm 1), thus concluding the Execution Phase. And the algorithm keeps at this process loop while the UE is connected (line 18 of Algorithm 1).

Algorithm 1: AHP HANDOVER ALGORITHM

```
1  ∀ UE
2  ∀ BS
3  BS activates HO Manager
4  UE connects to closest BS
5  UE requests video content
6  while UE connected do
7      HO Manager asks for measurement report
8      HO Manager receives beacons from UE (RSRP detected values)
9      HO Manager gets PDR and pMOS (from Serving and detected
         Candidates BS)
10     HO Manager initiates AHP calculation
11     for each detected BS do
12         Calculates AHP Score of detected BS
13     end
14     BestCellId = Cell Id with highest AHP Score
15     if $BestCellId != ServingCellId$ then
16         Execute Handover to BestCellId(Target Cell)
17     end
18 end
```

4.4 SER Handover - Measurement Phase

The measurement step involves around collecting three parameters to be used by the SER handover. The parameters can be seen at Figure 9, in an UML Aggregation relationship between classes. The parameters chosen are the Predictive Mean Opinion Score (named here as pMOS), the Packet Delivery Ratio (*i.e.,* PDR) and Reference Signal Received Power (*i.e.,* RSRP). Each one of these parameters represent a well-known group of parameters. PDR represents QoS, pMOS represents QoE and RSRP represents the radio signal strength parameter.

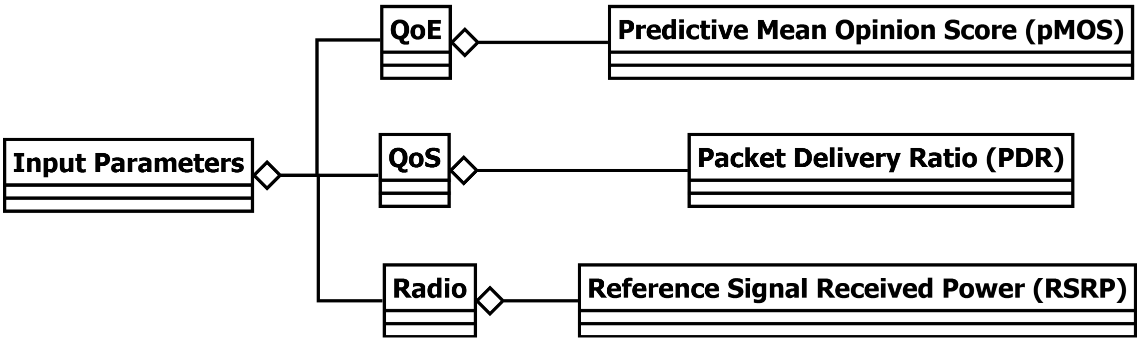


Figure 9: AHP Input Parameters

At the HO measurement phase, the HO Manager receives beacons from the nodes (UEs) and from the base stations, with which it can updates the measurement reports of all the active connections. To perform the handover, the proposed algorithm considers that the BS antenna is aware of the PDR and pMOS for each of the active connections (connection UE-BS). In this way, the HO Manager, that performs the HO algorithm, is able to calculate the mean of the PDR and pMOS from each BS, and includes each of these information at the handover decision. While the information from PDR and pMOS is reported by the BS, the information about the RSRP is reported from each UE to the handover manager.

For the Radio aspects, the algorithm considers the RSRP which takes into consideration the received power of a node. As stated in Chapter 3, RSRP is the parameter from signal strength indicator used at LTE Base Stations (called evolved Node B, *i.e.,* eNB) but reported by UE. RSRP is a RSSI type of measurement, but used exclusively by 3GPP. Generally, a higher RSRP value indicates that there is a good signal quality of a LTE BS for the UE to connect.

From Quality of Service, the chosen parameter is the PDR. As the name suggests (Packet Delivery Ratio), PDR is the ratio of packets that are successfully delivered to a destination compared to the number of packets that have been forwarded by the sender. This proportion is a good estimation about the network aspects of the UE-BS connection. In this dissertation, the packets delivered are related to the video application, and due to this, the packet contains frames information.

$$PDR = \frac{DelivPkt}{TotalPkt} \tag{4.1}$$

where:

$DelivPkt$ = Successful Delivered Packets
$TotalPkt$ = Total Sent Packets

From Quality of Experience, the selected parameter is pMOS. This metric is generated during a transmission from a server (BS) to a client (UE), given a certain GOP (Group of Pictures) value, of a certain video. The video has three distinct types of frames (I, P and B), and each one has distinct sizes and impact to the overall video in case of failure: frame I is the most important, followed by frame P and then frame B. The more I-P-B frames lost, the lower will be the Predictive MOS value, resulting to a worse quality of experience perceived by the user. The video composition can be seen at Figure 10.

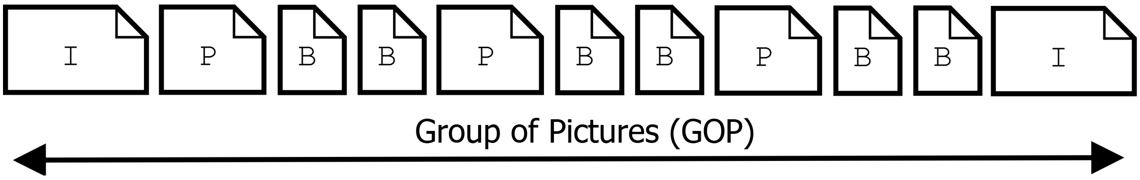


Figure 10: Video composition: frame types and GOP

This metric was built with the help of a machine learning classification technique. The Random Forest [47] technique works with the concept of forming smaller selections of a tree, reporting different results of those smaller trees, joining/counting all the answers and finding a majority answer for a question (in our case, the value of predictive MOS).

For the construction of the pMOS, an entire learning process (i.e., training, testing and validation) was carried out with a database of videos and MOS obtained through a subjective QoE test performed with the help of volunteers. To create the database for training, volunteers watched videos (with or without loss) and assigned a MOS value for each video. After building the database, it was possible to train the pMOS that correlated the amount of missing I, P, or B frames with the corresponding assigned MOS value (explaining the term Predictive from pMOS).

A QoE-aware decision-making assists in selecting a base station that can provides video transmission with better QoE. In this way, the proposed handover algorithm considers a QoE monitor running on the base station that has active connection with a user equipment. The monitor, by using the already trained pMOS technique, is able to calculate the estimated MOS of a video at run time based on the loss of frames information. The pMOS value helps to feed the AHP calculation and it is an essential criteria for SER handover.

4.5 SER Handover - Decision Phase

The AHP provides a structured technique for the decision making of problems with multiple parameters involved, by using pairwise comparison between the numerical values of each collected parameter and their relative degrees of importance, in order to adjust their weights of each parameter at run time. Higher weight means that greater importance must be attributed to a particular parameter. The defined levels of importance used are the same shown at Table 2 from Chapter 2.

Therefore AHP constructs for each node its own matrix to compare all parameters pairs according to their instantaneous values obtained. The Judgment Matrix is represented according to Equation 4.2, where it shows the pairwise comparison of the metrics and their importance relations with each other. In this matrix, as explained before in Chapter 2, if the PDR is 2 times more important than the pMOS, then the opposite comparison (pMOS to PDR) is 2 times less important.

$$\begin{array}{c} \\ PDR \\ pMOS \\ RSRP \end{array} \begin{array}{c} \begin{array}{ccc} PDR & pMOS & RSRP \end{array} \\ \left(\begin{array}{ccc} 1 & 2 & 4 \\ 1/2 & 1 & 2 \\ 1/4 & 1/2 & 1 \end{array}\right) \end{array} \tag{4.2}$$

In the guidelines remarking AHP Judgment Matrix definition, states that the level of importance in this pairwise comparison needs to be based upon the author's experience. However in this dissertation, some simulation results were also conducted to validate the initial Judgment Matrix and the different scale of importance between the parameters.

The Packet Delivery Ratio parameter was considered to be the most important for base station selection because its higher weight leads the Handover Manager to choose an antenna that can provide video transmission with better packet delivery support. In this situation of video dissemination in VANETs, it was noticed that the QoE parameter (pMOS) is highly dependent from the PDR good service due to the frames of the videos depend upon the good delivery of the packets.

Each video evaluated has distinct I-P-B frame size and consequently different video size. So *e.g.,* in the video called Container the frames I-P-B has distinct sizes and attributes. Frame I needs 8 packets to be delivered, P needs 3 packets and B needs just 1 packet. If one of the packets from a frame is lost, the whole frame set is considered to be lost and results to a decrease in pMOS value. Due to this, the packet delivery is very important for the good performance of video distribution and consequently has the biggest importance in handover selection.

While in homogeneous networks (and horizontal handovers) the Radio parameter is the most important, in the situation about heterogeneous network (of distinct cell sizes) it is not the most suitable anymore because a high congestion base station sometimes is not appropriate even if it has the biggest signal strength value.

Figure 11 summarizes the AHP decision at a set of hierarchical classes. The decision problem that it tries to answer is registered as Choose Best Cell, but can be explained as "Is there a better Cell to connect?". The criteria used to evaluate are the PDR (as QoS parameter), pMOS (as a QoE parameter) and RSRP (as a Radio parameter). The alternatives are always the serving cell (that the vehicle is currently communicating) and the other available base stations that were detected by the node beacon.

For each of these criteria, a specific calculation is performed to evaluate the different cells from the viewpoint of each criterion, *e.g.,* if the current cell has a PDR of 1, while the PDR of the candidate cell A is 0.7, then the current cell has greater weight in this criterion. Thus, there will be three minor calculations, ranking the alternatives under each criterion (one evaluating the cells in terms of PDR, another in terms of RSRP and another in terms of MOSp), as it was explained in details at the AHP example of Chapter 2. From the Judgment Matrix, it generates the corresponding AHP Vector of Priorities at Equation 4.3 and this Vector is consistent (Consistency Ratio of 0.1%).

$$\text{Vector of Priorities} = \begin{array}{r} \\ PDR \\ pMOS \\ RSRP \end{array} \begin{array}{c} Priorities \\ \left[\begin{array}{c} 0.571 \\ 0.286 \\ 0.143 \end{array}\right] \end{array} \tag{4.3}$$

In the end, the AHP multiplies the Equation 4.3 with the three minor calculations

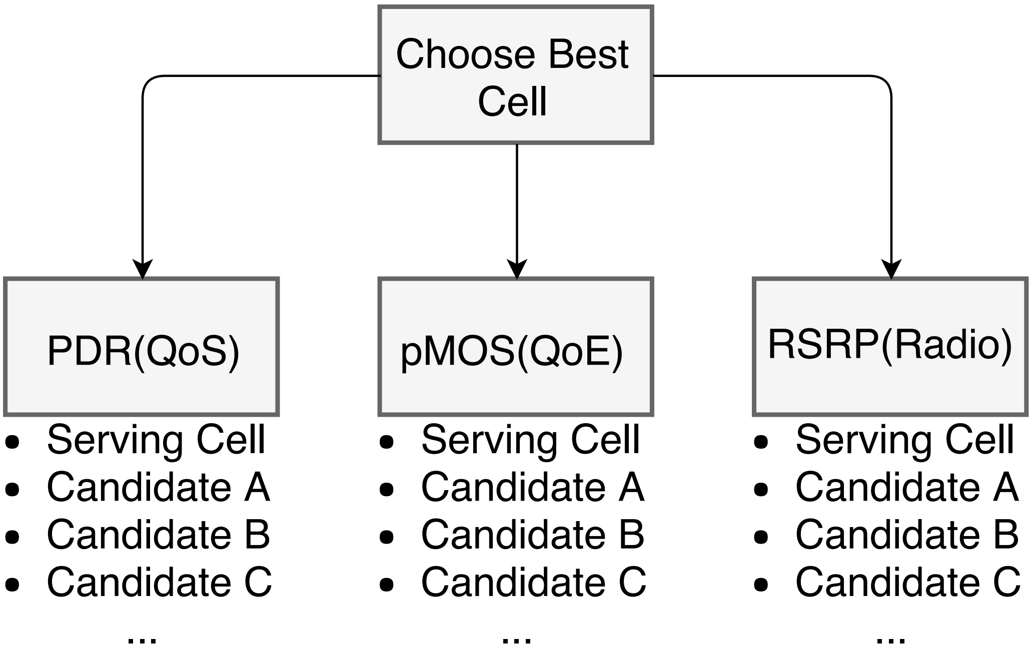


Figure 11: AHP Hierarchy for Handover problem

and obtains a weighted numerical result, which is called AHP score. The cell with the highest AHP score is elected as the cell with the best conditions to provide a reliable connection to that mobile node.

It is important to highlight that Equation 4.3 always presents this value, since it was defined during the criteria judgment (when the most relevant criteria for the good performance of the algorithm were chosen). However, the minor calculations are constantly updated according to the dynamic profile of the network through the measurements performed by the mobile nodes and cells.

4.6 SER Handover - Execution Phase

In this last step, the Handover Manager executes the order of the Decision Phase. As stated before, pMOS, PDR and RSRP information are important for the decision step of the proposed handover SER algorithm, which can evaluate if there is a better base station for the node to connect to.

If there is an antenna with better QoS, QoE and Radio conditions (resulting at a higher AHP score) for the vehicle, the Handover Manager selects a new antenna (*i.e.,* Target Cell) available to connect, and executes the handover of the node. Otherwise, the algorithm does not perform handover and the node remains on its Serving Cell.

Specifically, when the Handover Manager decides for a handover execution, it reports its decision to the Serving and Target cells detailing which mobile node will be transferred. Among the cells involved, some information are also transferred, such as information about the node itself. The handover at LTE cells is thus performed, in the form of hard handover, where the channel with the Serving cell is closed before establishing the new channel with the Target cell. After the handover execution, the algorithm step is concluded and the video distribution results must be analyzed at the simulation and evaluation steps in Chapter 5.

4.7 Chapter Conclusions

This Chapter focused on the presentation of this dissertation proposal: a new handover algorithm for vehicular heterogeneous networks. The SER functions and the algorithm was detailed for a better understanding of its operation: all coordinated by the Handover Manager entity. Now it is time for the evaluation of the proposal compared with other algorithms in Chapter 5.

CHAPTER 5

Evaluation Methodology

This Chapter is dedicated for the video assessment of the proposed handover algorithm for V2I scenario. Here it is discussed the use case evaluated and some important descriptions such as vehicles setup, videos used at the simulation, the full simulation description with the parameters used and presentation of results obtained along with analysis.

The evaluation consists of three fundamental steps: the generation of vehicular mobility, the communication of the network devices by the simulation, and the objective evaluation of the QoE performance metrics. The three steps are performed by distinct programs but are here presented in this chapter due to the work methodology.

5.1 Use Case Setup

The simulation consists of handover evaluation at VANET scenario. The simulation starts with nodes at a four-lanes highway of 3000 meters of length. The nodes evaluated represent different entities (low speed, medium speed and high speed vehicles) but generally follow the same trip route (to cross the whole highway) but depart following a random probability.

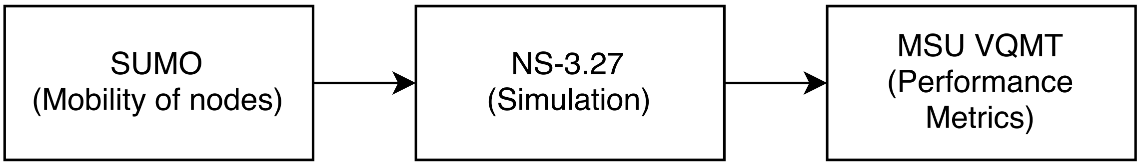


Figure 12: Evaluation Methodology

The nodes start traveling and, after some time, requests from the Base Stations

Parameter	Value
Mobility Simulator	SUMO
Number of Vehicles	150
Car Following model	Krauss
Vehicles Departure Time	Random
Trip	Cross the highway
Types of nodes	low, medium and high speed vehicles
Low Speed Vehicles	Mean: 10 km/h
Medium Speed Vehicles	Mean: 75 km/h
High Speed Vehicles	Mean: 145 km/h
Road Network	Highway, 3000 m
Simulation Area	9000 m^2

Table 5: Vehicles Parameters

at range for video consumption. All the Base Stations share the same video repository as was explained at Figure 8 from Chapter 4 (so the videos evaluated are the same in one simulation run) and are controlled by the Handover Manager (that executes the handover algorithms). The evaluation methodology steps can be seen at Figure 12.

The video application is run at Evalvid, which is a video application program. The Evalvid is installed on UEs (as a client) and Base Stations (as a server). After the requisition is reached at the Base Station, the message is transmitted to the HO Manager, that is responsible for receiving and answering the requisitions. In this simulation, the HO Manager accepts all the incoming requests and starts transmitting the video.

The video content is disseminated for the mobile nodes through the Base Stations at reach (each algorithm evaluated here has distinct behavior about what should be the serving cell for a node). If the HO Manager sees appropriate, it will execute a handover to a node according to the algorithm applied definitions. After the video is distributed, the simulation is finished. It was performed 33 simulation runs with different randomly generated seeds for each algorithm evaluated under each specific test. The results present the values with a confidence interval of 95%.

For the simulation of traffic and vehicle mobility, it is employed the Simulation of Urban MObility (SUMO)[48], which is an open source traffic simulator, that allows modeling the traffic with cars, buses, cyclists, pedestrians, among other things. SUMO helps to model and to manipulate such objects in the road scenario. This allowed the reproduction of the desired vehicle movements with random departure times.

The number of nodes used is around 150 and is formed by three types of nodes: low speed, medium speed and high speed vehicles. Each one of this users have distinct sizes, speed, acceleration and deceleration: prized by fidelity to the real world. The car following model is Krauss, which states how the moving vehicles (cars) will behave at the scenario. The details regarding the vehicles setup can be seen at Table 5. The generation of traffic exports an .xml containing the mobility of the vehicles for the evaluation in a

Parameter	Value
Number of cells (eNB)	9
Inter-cell distance	100m
Number of macrocell base stations	1
Number of small cell base stations	8
Macrocell Transmission Power	46 dBm
Small cell Transmission Power	23 dBm
Macrocell coverage area	1 km^2
Small cell coverage area	75 m^2
eNB DL Bandwidth	6 Resource Blocks
eNB UL Bandwidth	6 Resource Blocks

Table 6: Base Stations Layout and Specifications

simulator of computer networks.

Ns-3.27 [49] is a discrete-event network simulator for Internet systems. The vehicles/UE are equipped with full stack of LTE protocol in their On-Board Units (OBU) to allow communication with the other devices such as the base stations. The simulation follows some specifications from Lucca et al. [50].

The base station followed a specific layout of 9 cells: 1 macrocell base station and 8 small cell base stations. All the cells used are eNB (evolved Node B), which are responsible for serving 3GPP LTE access and coverage nowadays. The transmission power of macrocell base station is 46 dBm, while the transmission power for the small cell base station is 23 dBm.

However differently from the simulation from Lucca et al. [50], in this dissertation it was used a more challenging scenario for evaluation: consisting of decreasing the number of resource blocks from all base stations. The resource block relates to available bandwidth: which results at a scenario where the base stations are overloaded more easily.

The original specifications would lead to high simulation time (due to the need to increase both nodes and background data traffic to achieve the same challenging scenario). The specifications about transmission power was obtained according to definitions of Scenario A.1.1, established from 3GPP [51].

The main simulation parameters can be seen at Table 7. The simulation consisted of 60 seconds for each run. The transmission starts at 15 seconds (after the request from the UE and confirmation of HO Manager). The transmission ends around 50 seconds, which is an appropriate time to transmit all the requested videos. The propagation loss model used is Nakagami, which is a more realistic propagation model to be used at vehicular and mobile communication.

It was employed a background data traffic to increase the load to the infrastructure. Some nodes (called CBR nodes) were displayed and attached near random base stations to consume some random data traffic at the same time as the UE. The CBR

Parameter	Value
Network Simulator	NS-3.27
PHY / MAC	3GPP LTE
Transport Protocol	UDP
Propagation Loss Model	Nakagami
Users/Clients	UE(Vehicles)
Simulation Time	60s
Transmission Start	15s
Transmission End	50s
Packet Interval Frequency(CBR)	10ms
CBR Packet Size	2000 Bytes
CBR nodes	3
Repetition	33 times

Table 7: Simulation Parameters

nodes consume at a Constant Bit Rate the data traffic, and it has a certain packet interval frequency and packet size. The increase of packets' frequency leads to more congestion at the infrastructure.

In terms of video quality evaluation, Quality of Service (QoS) schemes alone are not necessary anymore to assess the quality level of multimedia applications, because they fail in capturing subjective aspects of video content related to human experience [7]. In this context, QoE metrics overcome those limitations, and thus we consider a set of well-known QoE objective metrics, namely Structural Similarity (SSIM) and Video Quality Metric (VQM). Both metrics are measured with the help of MSU Quality Measure Tool.

It was conducted simulations by transmitting different video sequences, *i.e.,* Container and Highway, downloaded from the video trace library [52]. The videos have durations of 10 seconds (and 20 seconds for Highway), are encoded with a H.264 codec at 300 kbps, 30 frames per second, and common intermediate format (352 x 288 pixels). The decoder uses a Frame-Copy method as error concealment, replacing each lost frame with the last received one to reduce frame loss and maintain the video quality.

Container due to the shorter time has fewer frames (300), while the longer Highway has 600 frames. The bit rate for the videos transmission is about 18 Mbit/s. Each packet size contains 512B. The different video sequences are selected to get a broader overview about the behavior of the handover algorithms when transmitting different videos sequences. Container and Highway also have distinct frame composition, enabling a distinct evaluation and performance by each algorithm. The videos parameters can be found in Table 8.

Parameter	Value
Application	Evalvid
Videos Sent	1 video for each connection
Videos Used	Container, Highway600
Videos Characteristics	H.264, 30fps, 352x288 pixels
Bit Rate	18 Mbit/s
Video Packet Size	512 Bytes

Table 8: Videos Parameters

5.2 Obtained Results

There simulations are separated in four subsections that contain different evaluation purposes. The simulation is separated in Distinct Videos Evaluation, Distinct Speed Evaluation, Effectiveness of Algorithms and Subjective Evaluation.

5.2.1 Distinct Videos Evaluation

The first category of video assessment is to determine how the three handover algorithms behave at a vehicular scenario when it is necessary to disseminate distinct videos: first the Container and then Highway. The two videos have some similarities, as already mentioned at Table 8, and have some differences: the videos have different GOP sizes and I-P-B frames compositions.

The purpose for this series of tests is to evaluate the handover performance and determine the most suitable algorithm for video dissemination. The other simulated parameters were already described at Section 5.1. And it is important to notice that it was simulated with 150 nodes (50 low speed, 50 medium speed and 50 high speed).

Figure 13 is the SSIM representation for the three handover algorithms evaluated. Higher SSIM value means better video quality. SER presents better video quality after the transmission when compared with RSSI-Based and PBGT algorithms, around 7-21% better results. One possible explanation for this is due to SER considering predictive MOS and packet delivery ratio at handover selection. RSSI-Based and PBGT algorithms did not present a satisfactory result: these SSIM values are consequence of a very bad transmission and the videos transmitted by both protocols did not obtain good QoE values, and it is possibly a video with lots of ghost frames and pixelization for the consumers.

Figure 14 is the VQM representation for the three handover algorithms evaluated. Lower VQM value means better video quality. SER proved to obtain strong results, about 15-32% better VQM values than the other two algorithms. SER prioritizes some idle and not congested cells that reflected at the lower VQM values obtained.

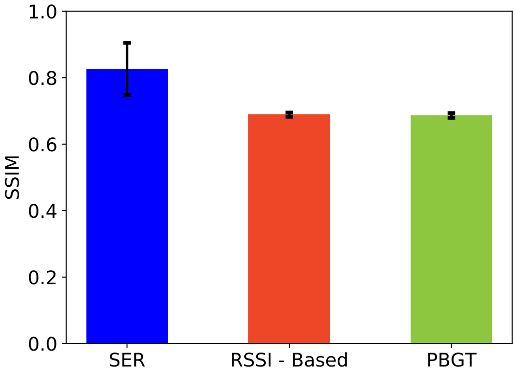


Figure 13: SSIM evaluation for video Container

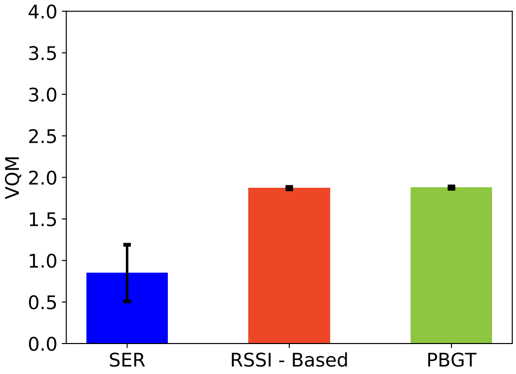


Figure 14: VQM evaluation for video Container

If there is a change in the video used, a new assessment must be performed. Highway is the biggest video used in this simulation. Figure 15 presents the SSIM values for the three algorithms at a vehicular scenario. SER achieved a great performance for the SSIM results, around 15-24 % better, in terms of luminance, contrast and structural similarity when compared with the others.

While the SER algorithm achieved a great SSIM result at the video transmission of Highway, its VQM counterpart did not show such great differences. however the SER handover still presented a better output, around 4-8%, compared with other algorithms as shown at Figure 16. Based on these series of tests, SER can attest to be the best suited algorithm for video dissemination at V2I scenario, even when simulated with distinct videos.

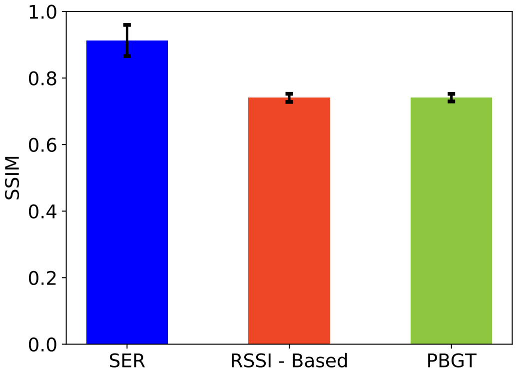


Figure 15: SSIM evaluation for video Highway

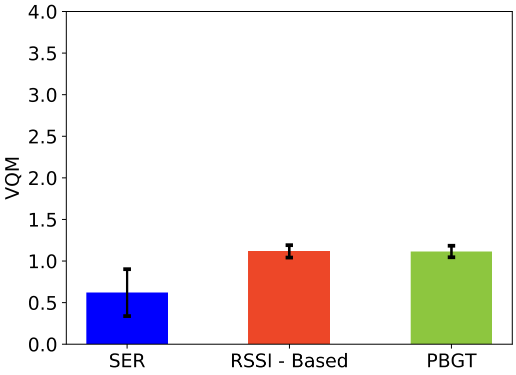


Figure 16: VQM evaluation for video Highway

5.2.2 Distinct Speed Evaluation

After the simulation with different videos, it is time to check the efficiency of video distribution for distinct speed of nodes. The simulation was performed with 150 vehicles, each time with distinct speed type: just high speed vehicles or just medium speed vehicles or just low speed vehicles. The video evaluated is the same for this series of tests: Highway. The objective of this assessment is to determine a correlation about how speed can affect at video delivery for the vehicles.

Speed is a big characteristic that distinguish vehicular nodes as special types of user equipment. However when the vehicle is very slow, it does not have many problems and can almost be treated as simple user device, *e.g.,* a simple pedestrian walking at a street and consuming a video. The mean SSIM values for the three algorithms was very good, especially for the SER algorithm that improves radically at the video distributed (circa 20% better) as confirmed at Figure 17. SER proves that is great for low speed nodes, almost obtaining the same video quality as the original uncompressed video before the transmission.

For the low speed vehicles, SER also showed great results, around 15-19% better output, as illustrated by Figure 18. When evaluating both Figures, it is possible to correlate that slow vehicles do not impose a big challenge for video distribution, due to the overall good quality from the three algorithms analyzed.

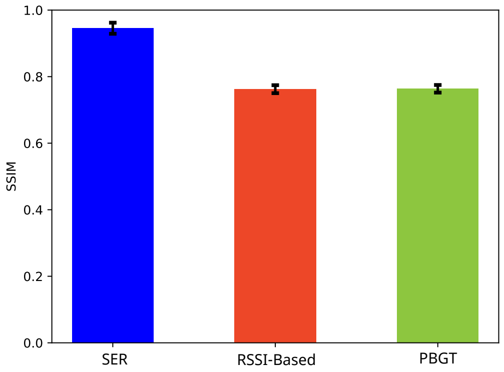


Figure 17: SSIM evaluation for low speed vehicles

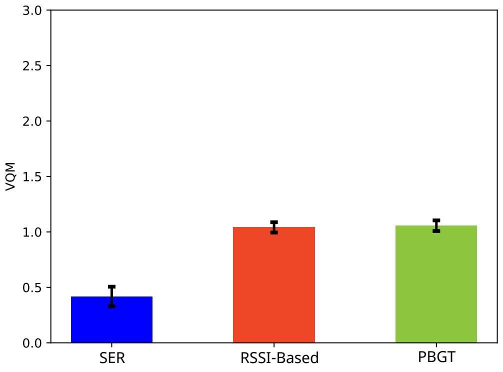


Figure 18: VQM evaluation for low speed vehicles

For medium speed vehicles, SER still presented higher quality videos but with a higher standard deviation range, as depicted at Figure 19. SER has better SSIM output, circa 12-22% better values than the competitors.

The SER VQM results for medium speed vehicles did not achieve way better values (just around 4%) when compared with other algorithms as demonstrated at Figure 20. SER still obtained better results possibly due to the broader parameter consideration at the HO decision phase. When the scenario consists of heterogeneous BS, the more detailed the decision (*i.e.,* in terms of more information), the more appropriate and suitable is the HO execution.

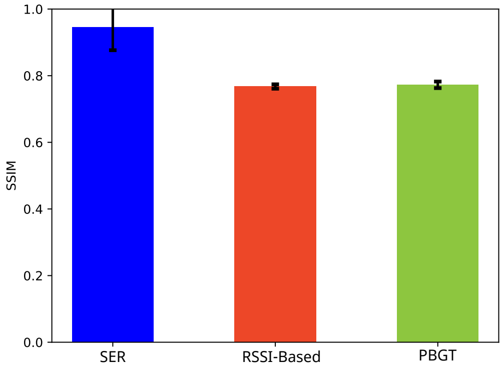


Figure 19: SSIM evaluation for medium speed vehicle

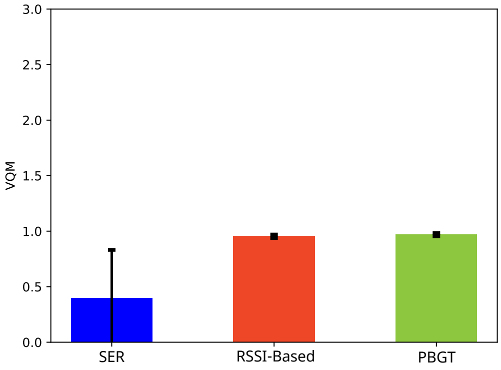


Figure 20: VQM evaluation for medium speed vehicles

At last, the high speed vehicles are simulated in terms of video dissemination as seen at Figure 21 and Figure 22. The results are very similar as the medium speed vehicles, however SER obtained better SSIM values (10-21%) and VQM results (from 3-20%).

The speed test can attest that as the vehicles become faster at the road, it turns the video dissemination to a more difficult task to accomplish. The higher speeds nodes still maintained a certain pattern at the results, but it is appropriate to say that it is a more challenging task and that SER seems the more prepared algorithm for such vehicular scenario.

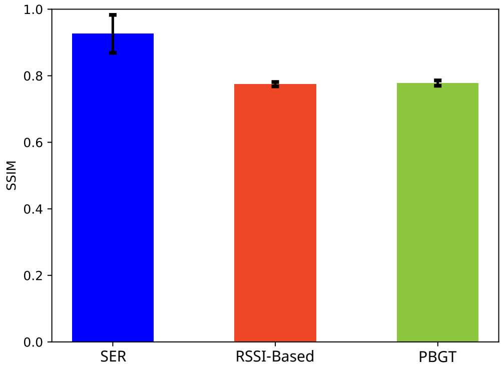


Figure 21: SSIM evaluation for high speed vehicle

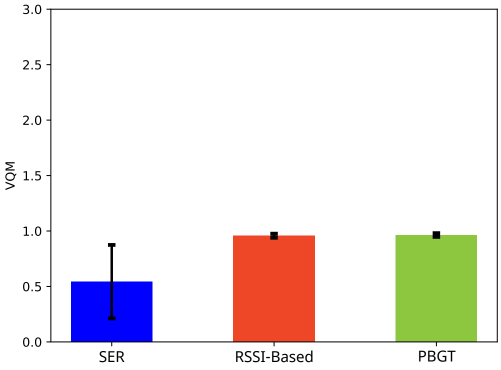


Figure 22: VQM evaluation for high speed vehicles

5.2.3 Effectiveness of Algorithms

After the QoE tests, it is appropriate to check the effectiveness of the algorithms in terms of number of handover executions. Figure 23 tries to compare the mean number of handover executions for the three algorithms. The test was performed for 150 nodes: 50 at low speed, 50 medium speed and 50 at high speed consuming Container video. SER has a higher number of handover registered than the other algorithms.

However a few things must be said: while SER mean value is still higher than the other algorithms, it is still an appropriate result considering from a total of 150 nodes, just an average of 15 vehicles perform the handover, which can be interpreted as just 10% of the nodes participated at the handover. This is a great ratio especially if it takes into consideration that the higher handover enabled the good performance for video distribution.

Handover generates a high signaling overload at the infrastructure but it is a essential component for the good quality of content dissemination and for the good quality of service and quality of experienced to the users. SER proves that it can generate a few more handovers but the trade-off is worthy, as confirmed at the previous SSIM and VQM results from the previous series of tests performed at Subsection 5.2.1 and Subsection 5.2.2.

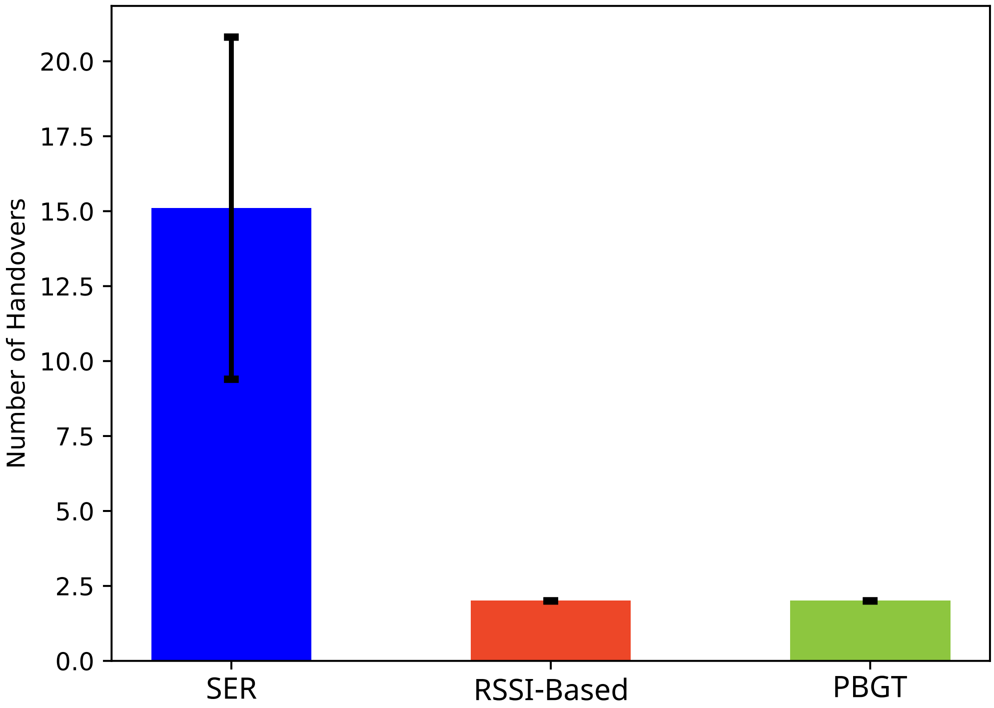


Figure 23: Number of Handovers for the three algorithms, 150 UEs

5.2.4 Subjective Evaluation

The last test consist of analyzing the frame distribution for the three algorithms. Figure 24 plots the three algorithms when disseminating the video Container and tries to associate chronologically the videos frames distributed with the corresponding SSIM values the algorithms obtained.

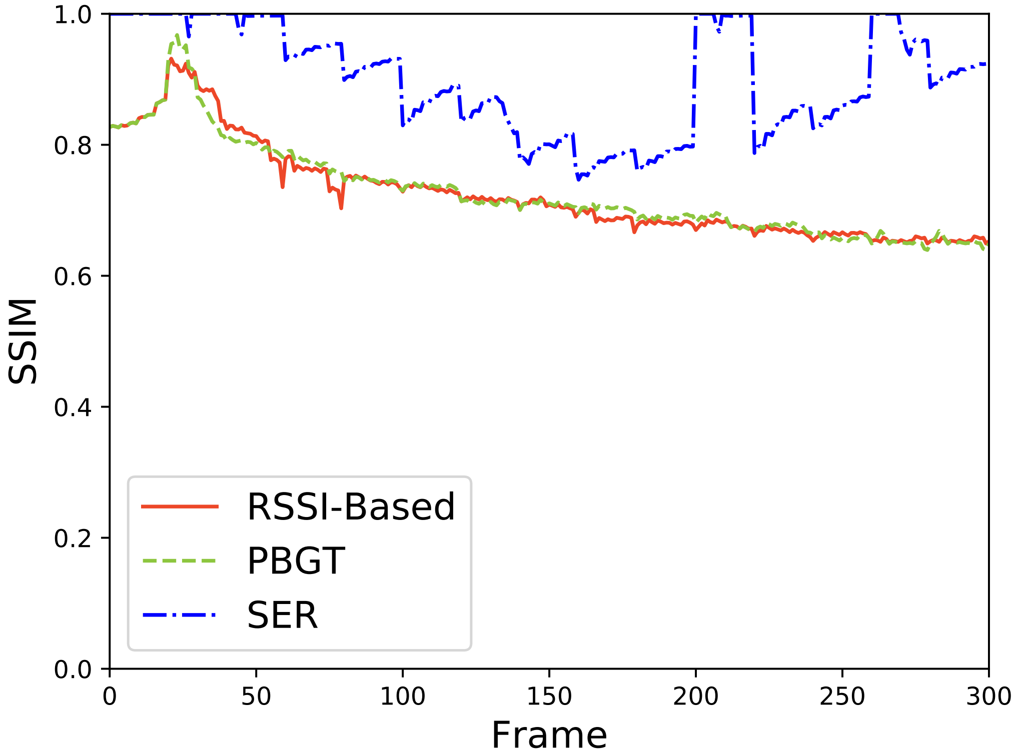


Figure 24: SSIM Timeline for Handover Algorithms

The three algorithms start with a good performance (more than 0.95 for SSIM) but decreases the quality along the time. However at frame #200, the SER SSIM drastically increased: possibly due to a handover performed at this same instant. From frame #200 until frame #250 the SER SSIM value increases: which confirms the good decision and handover. When reaching frame #260, SER performs a second handover and it keeps growing the SSIM result and ends with a great performance.

The RSSI-Based and PBGT algorithms did not perform a handover and apparently stayed connected at the same serving cell until the end of the transmission. The handover decision, as stated, is essential for mobile UE. Both RSSI-Based and PBGT algorithms registered overall bad SSIM values: possibly as a consequence from the bad connection between the UE-BS, or possibly due to interference suffered by the UE.

This SSIM Timeline confirms that the video quality and content dissemination is greatly affected by the handover algorithms and how the algorithms measures, decides and executes the handover process.

At last, it was selected a random frame (*i.e.,* frame #11) from the SSIM Timeline of the video Container, that was transmitted by each handover protocol to show the impact of transmitting video streams from the standpoint of the end-user, as displayed in Figure 25. Specifically, Frame #11 of the Container video sequence is the moment when the cargo ship is traveling at the sea (and a few objects are shown at screen like a bird, a white boat and a mast). This frame transmitted via SER has the same quality compared to the original frame, as it can be seen by comparing Figures 25(a) and 25(b). This makes the benefits of the SER algorithm for video transmission evident. On the other hand, the video delivered by PBGT and RSSI-Based algorithms are deteriorated, as shown in Figures 25(c) and 25(d). This is because this frame was lost, and also the previous ones, making it impossible to reconstruct based on the previously received frames and deteriorating the user Quality of Experience that watches a video with pixelization and freezing frames.

(a) Original (b) SER

(c) PBGT (d) RSSI-Based

Figure 25: Frame #11 Transmitted via Different Handover Algorithms

5.3 Chapter Conclusions

This Chapter provided the evaluation methodology to rank the handover algorithms performance under a series of tests. From the simulations obtained, it was proved that the SER algorithm achieves better video distribution at the heterogeneous vehicular scenario: even when changing the videos used or the vehicles speed. SER also proved that it performs a little bit more handovers, however it is worthy given the short percentage of handover for the scenario (just 10%). And in the end, it was depicted a SSIM Timeline along with the frames received from the standpoint of the consumer: and SER also confirmed to be a suitable algorithm.

CHAPTER 6

Conclusions

With the increasing demand for multimedia content, handover techniques based on just signal strength are no longer able to guarantee good Quality of Experience for users. Therefore, it was proposed SER handover algorithm that is aware of multimedia applications and managed by AHP calculation that takes into consideration several important parameters for a vehicular scenario.

It was verified that for this scenario of vehicular networks, SER Handover presents a better performance in the delivery of multimedia content. Its operation enables to determine the best cell to connect in a heterogeneous environment even if some of the neighboring cells presented higher signal strength.

Based on the simulation results, it can be deduced that there is a clear need to use distinct parameters at the decision for selecting a suitable cell to transmit multimedia content, in order to reduce the impact of mobility on QoE. However, it is necessary to make a precise choice, as shown by the SER superior video quality, due to the dynamic characteristics of the vehicular networks.

6.1 Future Works

As future work, it is expected to evaluate the algorithm with other more demanding videos from the mobile infrastructure. Another alternative for future work is the use of a intelligent method (*e.g.,* fuzzy or artificial neural networks) at the determination of AHP importance scales and turn the process into a more adaptive/dynamic selection based on the current network nodes and applications demands.

Other alternative can be the use of AHP aggregated with other parameters, *e.g.,* vehicle speed or network load. And the other option for extension of this dissertation is for more comparison between SER with other handover algorithms from research literature (that use QoE) or compared with other MCDM solving techniques.

6.2 Published Works

Part of the results of this master's dissertation were published at conference papers [53, 54, 55]. Other works were also published [56]:

1. **I. Medeiros**, L. Pacheco, D. Rosário, and E. Cerqueira, "Handover em redes heterogêneas baseado em ahp para transmissão de vídeo," *Anais da XVI Escola Regional de Informatica Norte 2 (ERIN II 2017)*, September 2017.
2. **I. Medeiros**, L. Pacheco, D. Rosário, J. Nobre, and E. Cerqueira, "Algoritmo de handover ciente de qualidade de experiência e qualidade de serviço em redes veiculares heterogêneas," in *ERAD/RS 2018 - Fórum de Pós-Graduação*, April 2018.
3. **I. Medeiros**, L. Pacheco, D. Rosário, C. Both, J. Nobre, E. Cerqueira and L. Granville, "Handover Ciente de Qualidade de Experiência e Qualidade de Serviço para Transmissão de Vídeo em Redes Heterogêneas," in *XXIII Workshop de Gerência e Operação de Redes e Serviços (WGRS - 2018)*, May 2018
4. **I. Medeiros**, W. Junior, D. Rosário, E. Cerqueira, T. Braun, and L. Villas, "A comparative analysis of platoon-based driving protocols for video dissemination over VANETs," in *2018 IEEE International Conference on Communications Workshops (ICC Workshops): 5G and Cooperative Autonomous Driving (ICC 2018 Workshop - 5G/Auto Dr)*, Kansas City, USA, May 2018.

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