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A Study on Geolocalization through GSM Systems

Work presented in partial fulfillment of the requirements for the degree of Bachelor in Computer Science.

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RESUMO

Este projeto visa mostrar, através de simulação, o quão eficaz um sistema de localização por sinal de GSM funcionaria na savana africana, e também fazer uma estimativa do alcance e de quantas estações são necessárias para cobrir uma determinada área. Este sistema usa a intensidade (RSS) e o tempo de chegada (TOA) do sinal recebido de diferentes estações fixas GSM, cujas localizações são conhecidas para calcular a localização de uma estação móvel.

Esta pesquisa é parte do projeto Smart Savannah, em que uma gama de diferentes sistemas de vigilância são desenvolvidos para proteger animais selvagens como rinocerontes e elefantes de caçadores ilegais. Este sistema de localização pode ser usado para detectar e localizar estes caçadores furtivamente, e poderia ainda, ser usado em missões de busca e resgate para estimar posições de celulares de pessoas desaparecidas ou de drones de vigilância perdidos.

Palavras-chave: GSM. Simulação. Triangulação. Geolocalização. RSS. TOA.

ABSTRACT

This project aims to show, through simulation, how effectively a GSM based localization system would work in the african savannah, it also estimates the range, and how many stations it takes to cover a determined area. This system uses the Received Signal Strength (RSS) and the Time of Arrival (TOA) from different GSM Fake Base Stations (FBS), whose locations are known, to calculate the location of a MS.

This research is part of the Smart Savannah project in which a wide range of different surveillance systems are developed to protect rhinos, elephants and other endangered wildlife from poachers. This localization system can be used to detect and localize these poachers in an unobtrusive way, in addition, it could be used in Search And Rescue (SAR) operations to estimate the positions of cellphones of missing persons or missing drones used for surveillance.

Keywords: GSM. Simulation. Triangulation. Geolocalization. RSS. TOA.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
BS	Base Station
BTS	Base Transceiver Station
FBS	Fake Base Station
GPS	Global Positioning System
GSM	Global System for Mobile communications
MS	Mobile Station
RSS	Received Signal Strength
RSSI	Received Signal Strength Indication
AOA	Angle Of Arrival
TA	Timing Advance
TO	Timing Offset
RTT	Round Trip Time
TOA	Time Of Arrival
TDOA	Time Difference Of Arrival
SAR	Search And Rescue
SNR	Signal to Noise Ratio
dBm	Decibel-miliwatts
KWS	Kenya Wildlife Service

CONTENTS

1 INTRODUCTION

This thesis contains a feasibility study on an unobtrusive tracking of GSM cell phones (MS) through the use of Fake Base Stations (FBS), using Time of Arrival (TOA) or Received Signal Strength (RSS) methods, in the Ngulia Rhino Sanctuary to locate poachers or missing persons, and even missing surveillance drones. Unobtrusive in this context means that no additional hardware or software are needed in the MS for the system to work. These evaluations are done with the use of an RF propagation simulation software.

1.1 Motivation

Poaching of african wildlife, particularly of white rhinos, black rhinos and elephants, has been escalating in the last decades, mostly for their horns and ivory tusks. Rhinos horns, although being made of the same material as our hair and fingernails, in some parts of the world are wrongly thought to have incredible medicinal properties and are sold in the black market at a price of more than 50,000 US dollars per kilogram, which is higher than the price of gold. Because of this demand, in some places even helicopters are used by poachers, and of a population that was once close to one million animals, today only 20,000 white rhinos and less than 5,000 black rhinos remain.

1.1.1 Smart Savannah project

In order to help combat poaching in the african savannah, Linköping University started a project, as part of a large research initiative called Security Link [17], to develop surveillance technology and innovation at wildlife sanctuaries and national parks creating a holistic solution that they call Smart Savannah.

The first deployments of this project are being made in the Ngulia Rhino Sanctuary, which like many of the parks and reserves in Kenya is protected by the Kenya Wildlife Service (KWS). The KWS was established in 1990, and employs anti-poaching rangers to combat local wildlife poaching. But since the rangers are poorly equipped, the Smart Savannah project aims to assist them, giving the technology needed to fight those crimes.

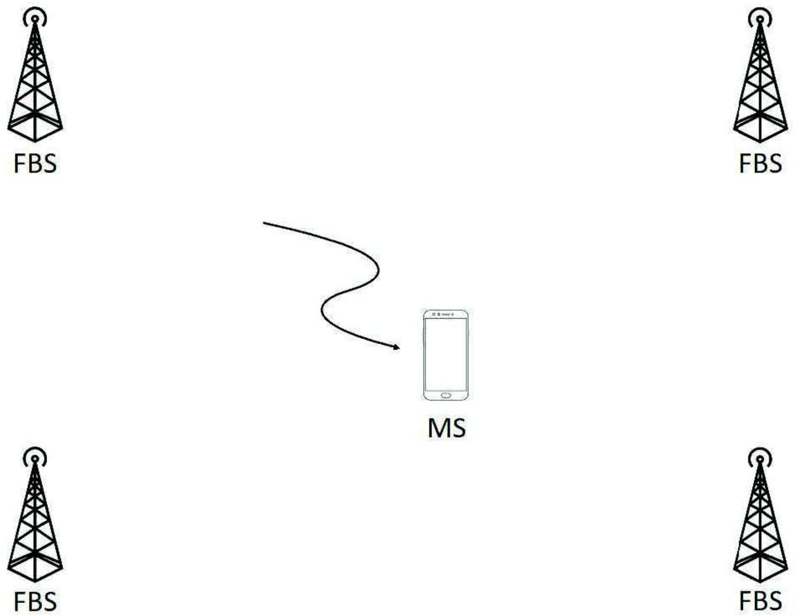
Figure 1.1 - App developed by the Smart Savannah project to help the rangers

There are already two earlier localization studies in this project, the first one was done by Jacob Sundqvist and Jonas Ekskog and used Received Signal Strength (RSS) of a cell phone WiFi system to locate it by circulating the area of interest, which means that it needs the phone to have the WiFi Hotspot mode on, continuously transmitting, to allow the system to work. The second one was done by Simon Pålstam and compared TOA and RSS localization methods with GSM radios and is further discussed in chapter 3.

1.2 General objective

The main objective of this thesis is to evaluate, in a simulation environment, the accuracy of an unobtrusive localization system that uses a network of GSM Fake Base Stations (FBS) with known position to locate a Mobile Station (MS) through trilateration. That MS can be a poacher carrying a cellphone, a missing person, or even large animals with localization tags.

Figure 1.2 - GSM Localization schematic



The other goal of this thesis is to compare two different methods to estimate the distance from the FBS to the MS in order to localize the MS, those methods are Received Signal Strength (RSS) and Time of Arrival (TOA).

2 THEORETICAL BACKGROUND

2.1 Electromagnetic Waves Propagation

When an electromagnetic wave travels through space, it suffers attenuation because it's energy is dispersed. In free space, if you consider an isotropic antenna, this attenuation (L_{fs}) is given by (1), where λ is the wavelength and d is the distance travelled.

$$L_{fs} = 20 \log \left(\frac{\lambda}{4 \pi d}\right)^2 \text{ (dB)} \quad (1)$$

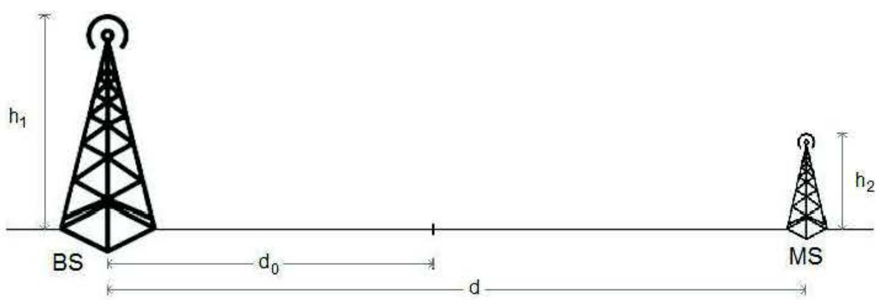
In the real world though, there are reflections and absorptions from the ground that alter propagation, because of that, the following approximation to estimate path loss must be used [9]. First d_0 is calculated, which is given by equation (2) where h_1 and h_2 are the heights of the transmitting and receiving antennas, then when the distance is lower than or equal to d_0 equation (3) is used and when the distance is higher than d_0, equation (4) is used .

$$d_0 = \frac{12\, h_1\, h_2}{\lambda} \quad (2)$$

$$L_{dB} = -20 \log\left(\frac{4\pi d_0}{\lambda}\right) - 20 \log\left(\frac{d}{d_0}\right) \qquad d \leq d_0 \quad (3)$$

$$L_{dB} = -20 \log\left(\frac{4\pi d_0}{\lambda}\right) - 40 \log\left(\frac{d}{d_0}\right) \qquad d > d_0 \quad (4)$$

Figure 2.1 - Illustration of equation (2)



Based on (3) and (4), the relation between the transmitted and received power can be obtained as shown in equations (5) and (6).

$$P_R = P_T \left(\frac{\lambda}{4\pi d}\right)^2 \qquad d \leq d_0 \tag{5}$$

$$P_R = P_T \left(\frac{\lambda d_0}{4\pi d^2}\right)^2 \qquad d > d_0 \tag{6}$$

Isolating d from equations (5) and (6), equations (7) and (8) are obtained:

$$d = \frac{\lambda \sqrt{P_T}}{4\pi \sqrt{P_R}}, \quad d \leq d_0 \tag{7}$$

$$d = \sqrt{\frac{\lambda d_0 \sqrt{P_T}}{4\pi \sqrt{P_R}}}, \quad d > d_0 \tag{8}$$

2.1.1 Decibel-miliwatts

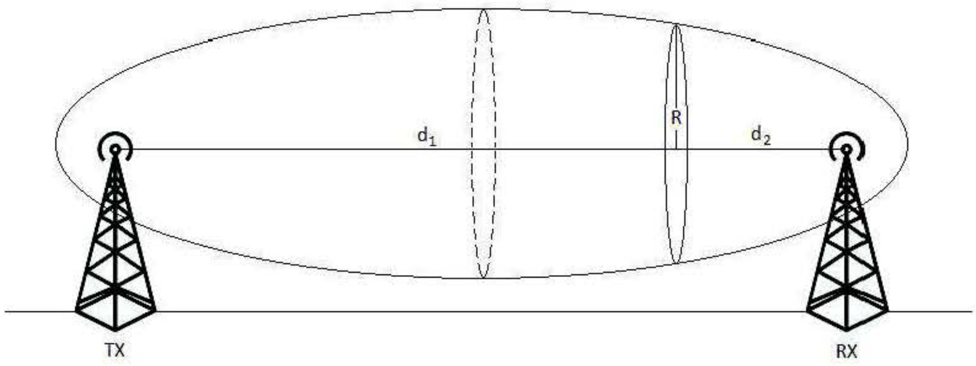
Decibel-miliwatts (dBm or dBmW) is a measurement unit used mainly in telecommunications to express the absolute power in a logarithmic scale, it is defined as the decibel power level in relation to 1mW. It is expressed by (9), where P is the power in watts and P_{dBm} is the power in dBm.

$$P_{dBm} = 10 \, log_{10} \left(\frac{P}{1mW}\right) \tag{9}$$

2.1.2 Fresnel zones

Named after physicist Augustin Jean Fresnel, the Fresnel zones are a series of three-dimensional concentric ellipsoids that encompass both the transmitter and the receiver antennas. The first Fresnel zone is particularly important to the study of the viability of a link when the path is obstructed.

Figure 2.2 - Fresnel ellipsoid



The radius (R) of the *n*th Fresnel zone ellipsoid shown in figure 2.1 at a distance d_1 from antenna 1 and d_2 from antenna 2 is given by equation (10), where λ is the wavelength. To ensure that the link is not significantly affected by signal blockage, diffraction or multipath attenuation, any obstacle must be at least 60 percent of R_1 (radius of the first Fresnel zone) from the line of sight path.

$$R_n = \sqrt{\frac{n\, d_1 d_2\, \lambda}{d_1 + d_2}} \tag{10}$$

2.2 Trilateration

While triangulation determines the location of a point by measuring angles, Trilateration does it by measuring the distances to the point. In the case of a two-dimensional space, which can be a station on the ground, you need at least three measurements from three different stations with known coordinates to determine a location, on the other hand, if you want to take into account the altitude of that station, you need at least four measurements to find its location.

For the trilateration using the estimated distances from RSS or TOA measurements, the equations for the circles centered around the stations from which the measurements were taken are used, with radiuses equal to the measured distances themselves. So the equation system for a two-dimensional space is as follows:

$$\begin{aligned}(x-x_1)^2+(y-y_1)^2&=d_1{}^2\\(x-x_2)^2+(y-y_2)^2&=d_2{}^2\\(x-x_3)^2+(y-y_3)^2&=d_3{}^2\end{aligned} \qquad (11)$$

Where x_1, x_2, x_3 and y_1, y_2, y_3 refer to the location of the stations and d_1, d_2, d_3 are the estimated distances. Since those measurements contain an error, if they were applied directly to the equations above, in most cases, an unsolvable system of equations would be generated because the three circles would not cross at a single point. In order to prevent this, a third variable k multiplying d_1, d_2 and d_3 is added so that there are three equations and three variables and then a solution for x and y will always be found.

$$\begin{aligned}(x-x_1)^2+(y-y_1)^2&=(k\,d_1)^2\\(x-x_2)^2+(y-y_2)^2&=(k\,d_2)^2\\(x-x_3)^2+(y-y_3)^2&=(k\,d_3)^2\end{aligned} \qquad (12)$$

2.3 - Radio localization methods

The four most common methods that can be used for radio localization are Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Received Signal Strength (RSS), while AOA and TDOA require specific antennas and other hardware to work, TOA and RSS are already available in the GSM protocol. Because of that, TOA and RSS are the methods discussed in this work.

2.3.1 - TOA in GSM

Time of Arrival (TOA) is the time it takes an electromagnetic wave to travel between the transmitter and the receiver, since it is known that radio waves travel at the speed of light, that distance can be estimated using equation (13), where c is the speed of light and T is the TOA measured.

$$d = c * T = 3.10^8 * T \qquad (13)$$

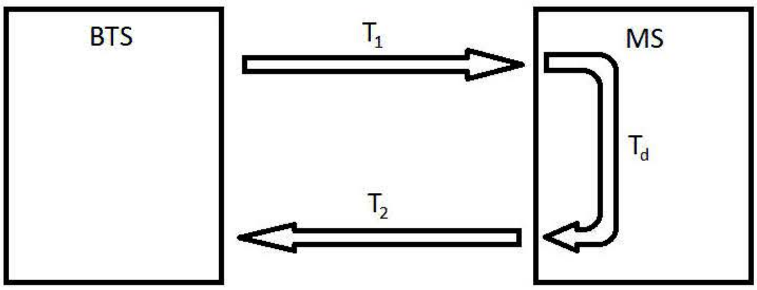
2.3.1.1 Timing Advance

Timing Advance is a parameter specified in GSM 5.10 [7] used for time alignment of different mobile stations communicating with the BS, its value is defined by the BS based on its distance to the MS and then sent to the MS so that it knows when to transmit its frame and can also be used to determine the distance between the MS and the BS. It is an integer value from 0 to 63 and each increment implies an increment of one bit period, which is $48/13\mu s$ to the advance on the MS. When the TA is 0, the MS-BS transmissions are 468.75 bit periods behind, while when TA is 63, they are 405.75 bit periods behind [7].

2.3.1.2 Round Trip Time (RTT)

In order to know how far a MS is from the BS and determine the TA, the BS has to measure the Round Trip Time (RTT), the RTT is the sum of T_1, T_d and T_2. While T_1 is the time it takes the electromagnetic wave to travel from the BS to the MS, T_2 is the time it takes to travel the other way around and T_d is a pre-specified delay between the time the MS receives the BS transmission and the time it responds back to the BS.

Figure 2.3 - RTT measure in GSM



While T_1 and T_2 depend only on the BS-MS path, T_d is expected to be (468.75 - TA) multiplied by a bit period, which is $48/13\mu s$.

2.3.1.3 Timing Offset (TO)

Based on the difference between the RTT measured and the RTT expected if T_1, T_2 and TA were equal to zero, the value of the Timing Offset (TO) in bits can be obtained, as shown in equation (14), where the 468.75 bit periods is the delay for MS-BS transmissions when TA is zero, as specified in GSM 5.10 [7] .

$$TO = RTT - 468.75 = (T_1 + T_2 + 486.75 - TA) - 468.75 = 2 * T - TA \qquad (14)$$

Although TO is specified to have an accuracy of at least 1 bit, which would be close to 3.69μs, or 550m, most BTS equipment provide much better accuracy, and the FBS used at Linköping University [13] provided an accuracy of at least 1/20 bit periods, which corresponds to about 27 meters [16]. Knowing TO and TA, the TOA can be calculated as shown in equation (15).

$$TOA = \frac{TO + TA}{2} \qquad (15)$$

2.3.2 - RSS in GSM

As defined in ETSI TS 125 215 - Physical layer specification [8], the Received Signal Strength Indicator (RSSI) is the time-averaged power measured over one time slot, it is given in dBm at the antenna connector and at a resolution of 0.5 dB.

While the BTS transmits with constant power, the MS transmit power varies to keep the the received power at the BTS constant. The algorithm to control the power at the MS is called Power control loop and is defined at GSM 5.08 [6] and the BTS knows the power level of the mobile stations that have a connection established with it.

3 RELATED WORK

Comparing this work with other related radio localization researches, there are different approaches to this problem, some use a database of previous measurements to determine a signature to every point and then finds the location by comparing the RSS measured to this database, this method works better in urban areas, where you have determined paths to follow. Other approach is to calculate the location using the difference in the measured RSS from different stations, this approach should work better in environments without many obstacles.

A research at Linköping University [13], also part of the Smart Savannah project, conducted practical experiments with the use of both RSS and TOA measurements to locate a mobile station in two environments, first at open field and short distances, and then in a park with similar terrain to the savannah and distances up to 115m. It was concluded that at open field, the TOA method showed slightly better accuracy, while in the park, both methods showed similar results, which were much worse than in the first case.

A team of researchers from the National Taipei University of Technology published an article named "Mobile Location Estimation Based on Differences of Signal Attenuations for GSM System" [5] which proposed a method to determine the location of a mobile station in an urban environment using the difference in RSS measured from different Base Stations. First they evaluated the method with simulation, using the SignalPro software package by EDX Engineering Inc. and then they verified its accuracy in a real GSM system in urban Taipei City. The results obtained with the proposed method were better than the Cell-ID method of a real GSM system.

A study at University of Hannover, compared the accuracy of different methods of GSM device localization in dense urban scenarios, where GPS signal is not available or not very accurate in an article named "On the Accuracy Improvement Issues in GSM Location Fingerprinting" [19]. The methods compared were based on neural networks localization (NN), database correlation and dead reckoning. The study concluded that a tracking algorithm using neural network positioning results and an extended Kalman filter (EKF) to eliminate measured noise supplied the best results with mobile users.

A research team from VTT Information Technology in Finland has published an article named "Location of GSM Terminals using a Database of Signal Strength Measurements" [10], which describes an experiment using a signal strength Database Correlation Method (DCM) to determine the location of a mobile station moving in the center of Helsinki. From these experiments, they were able to conclude that the method is a competitive alternative, giving a mean location error of 43 meters and few clearly deviated results.

Researchers from UFRGS developed a project named "Practical Issues in Wireless Sensor Network Localization Systems using Received Signal Strength Indication" [12] that studied and elaborated a localization system using a wireless sensor network (WSN) and the RSSI measurements and since the stations were very close to each other, reflexion was not a factor. With 3 sensor nodes, they were able to locate the target with a mean error of 2.21 meters, while with 4 nodes, the mean error stayed at 1.85 meters.

A student from UFPR [4] evaluated the use of GSM geolocalization as an alternative to GPS systems, in his research he used the Timing Advance (TA) parameter, which is available to the mobile station, in relation to three different BTSs to calculate the MS position. Timing Advance is a parameter used to synchronize transmissions of different MS and has a resolution of 3.69μs, which represents steps of 550 meters. Because of the low resolution of the measurement, the article concluded that although it can be used to estimate someone's location, its precision is nowhere near the one provided by GPS or other satellite based localization systems.

Table 3.1 - Overview and comparison of related work

Approach	Uses simulation software	GSM signal for localization	RSS	TOA	Compares to a database of measurements	Accuracy
Radio Localization with GSM [13]		X	X	X		~78m

Mobile Location Estimation Based on Differences of Signal Attenuations for GSM Systems [5]	X	X	X			Urban: ~50m Suburban: ~200m
On the Accuracy improvement issues in GSM Location Fingerprinting [19]		X	X		X	~50m in most cases
Location of GSM Terminals using a Database of Signal Strength Measurements [10]		X	X		X	~43m
Practical Issues in Wireless Sensor Network Localization Systems using Received Signal Strength Indication [12]			X			~2m with stations 10m apart
Localização Geográfica Através de Aparelho Celular [4]		X		X		~550m

4 EVALUATING A NETWORK OF FBSs TO LOCATE POACHERS

This chapter describes how the experiments were performed, the details of the terrain at the Ngulia Rhino Sanctuary, the ICS Telecom simulator and the methodology used for the simulations, including the simulation parameters, how the measurements were obtained and then used to calculate the locations.

4.1 Scenario

The Ngulia Rhino Sanctuary is a savannah situated in the Tsavo West National Park in Kenya and has an area of approximately 35 square miles (90 square kilometers) with grassy landscape and scattered trees, this area is surrounded by an 1 meter high electric fence.

Figure 4.1 - Ngulia Rhino Sanctuary

The sanctuary terrain is between 600 and 800 meters above sea level and lies beside the 1800 meter high Ngulia Hills. Between the Hills and the Sanctuary, there is also the

Ngulia Lodge which is a hotel that sits at an elevation of around 200 meters above the sanctuary and has a very good view of the area. The image below shows the elevation profile of the sanctuary terrain.

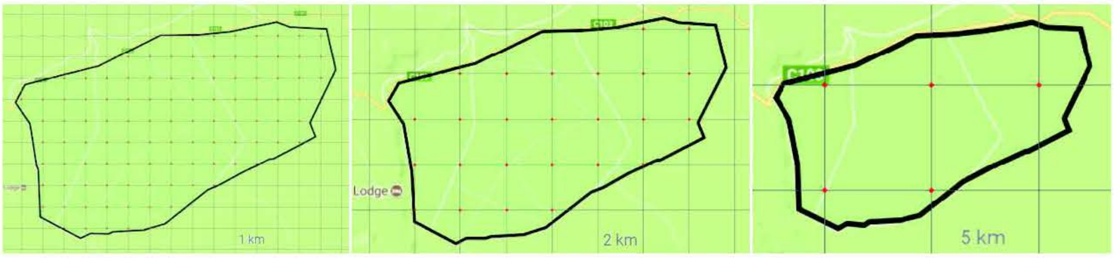
Figure 4.2 - Terrain elevation profile

4.2 Determining the distance between FBSs

To determine the distance between stations for the simulation, two factors must be considered. First, if the stations are too far apart, a good signal of enough stations to determine the location of the target may not be available, on the other hand, if the distance is reduced too much, the system may end up with too many stations and the project would become unfeasible.

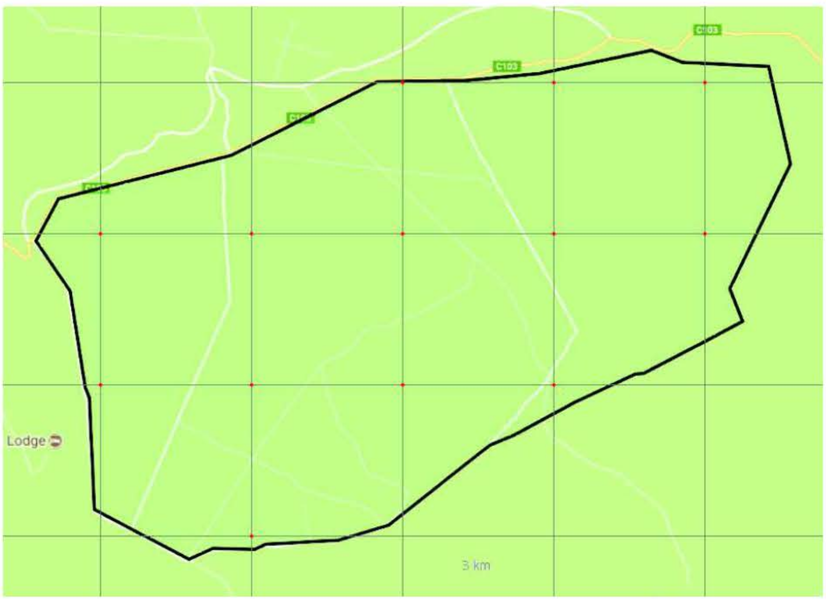
So, to determine that distance, in the first step, three different scenarios were envisioned, with distances of 1 km, 2 km and 5 km between stations and the images below show those stations plotted on the Ngulia Rhino Sanctuary map. While the 1km and 2km scenarios would require too many stations, with 104 and 23 respectively, the 5km scenario, while requiring only 5 stations, would not provide good accuracy since a good portion of the sanctuary would only be covered by one station.

Figure 4.3 - 1, 2 and 5 km between stations



Therefore, a fourth scenario was plotted, with 3 km between stations, in this case, only 13 stations would be required and the whole sanctuary would be covered by at least three stations, reaching a good compromise between the two factors. Thus, it was decided that the fourth scenario would be used and the simulations were done with a distance of 3 km between stations.

Figure 4.4 - 3 km between stations



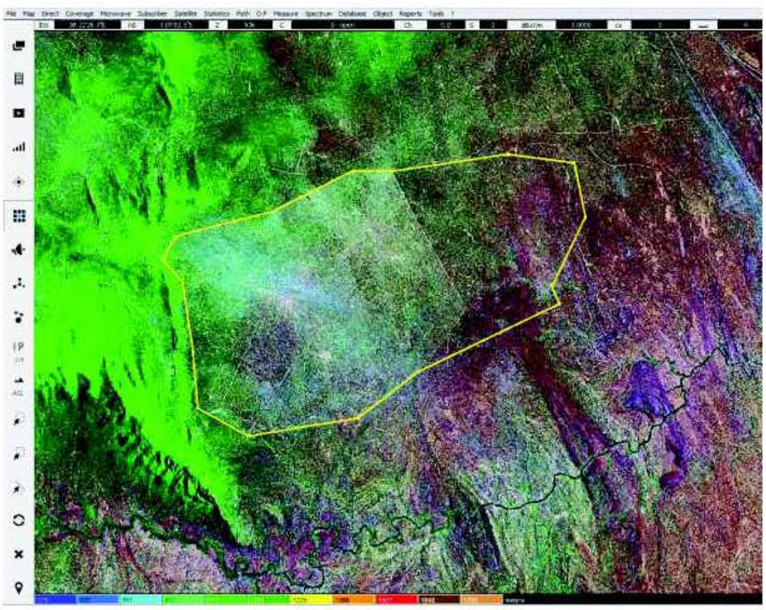
4.2.1 Fake Base Station (FBS)

A Fake Base Station (FBS), for the purposes of this experiments, is a fixed station that emulates the functions of a real carrier BTS but does not provide any real telecommunications service. It is there to connect to any mobile station (MS) to get the necessary measurements to determine its distance, and then transmit that information to another FBS or a command center, that then uses that distance measured from different FBSs to estimate the MSs geographic position.

4.3 ICS Telecom simulator

All of the experiments in this work were done using ATDI ICS Telecom at ANATEL. ICS Telecom is a telecommunications simulation software based on cartographic data, it aims to help design, optimize and evolve radio and microwave networks, and to support the regulation of frequency spectrum from a technical analysis perspective. Since all the simulations used in this work were of a deterministic nature, no random seed was used.

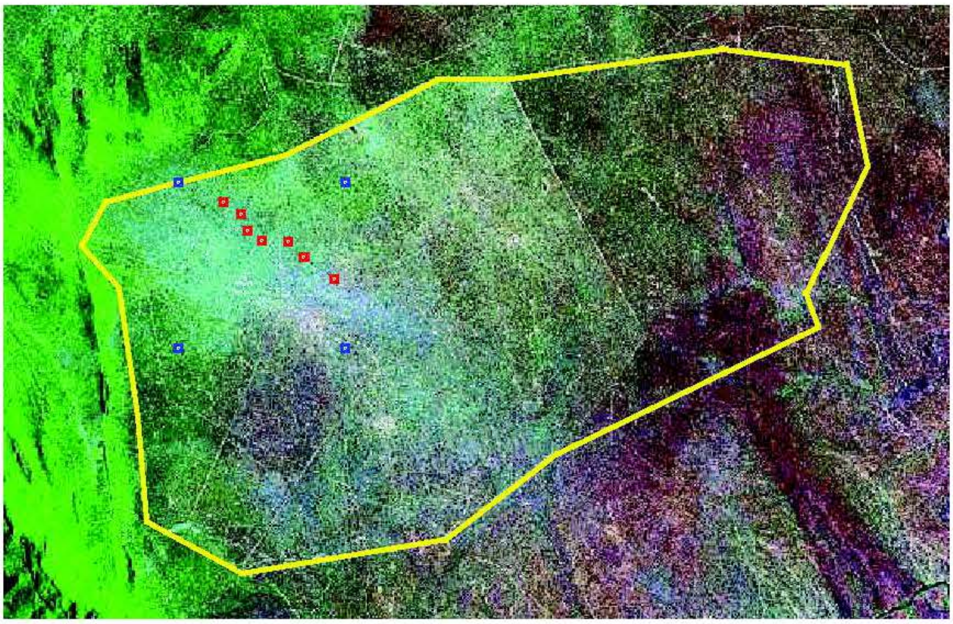
Figure 4.5 - Ngulia Sanctuary map in the simulator



4.4 The experiments

In this section the experiments performed as a basis for this feasibility study are described in details. In order to evaluate the accuracy of the localization system, the MS is placed in different places inside a grid of FBSs as if it was following a path, and at each place measurements of RSS and TOA are taken to estimate and compare those two localization methods. The image below shows the disposition of the FBSs and the positions where the MS was tested in the map. The FBSs are shown in blue, the MS in red and the Ngulia Rhino Sanctuary limits are shown in yellow.

Figure 4.6 - Disposition of the FBSs and MS for the experiments



4.4.1 Simulation parameters

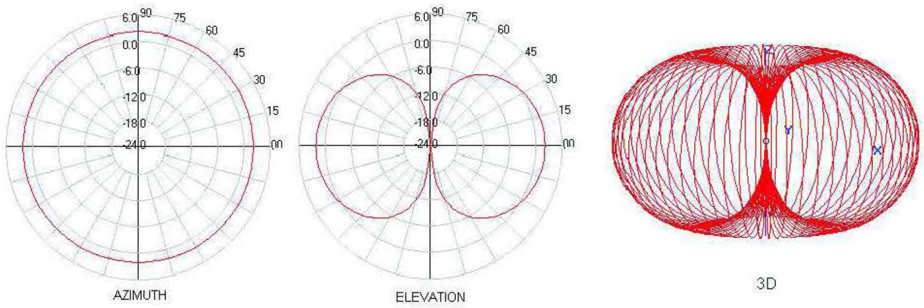
All the experiments in this chapter used the same simulation parameters, those parameters are separated between environment parameters, and simulation model parameters. Environment parameters are things like terrain elevations, type of the antennas, height of the towers, frequency used and power emitted, while simulation model parameters are things like the propagation methods, diffraction geometry, subpath attenuation and reflection model.

For the environment parameters, a 3D map of the Ngulia region with a resolution of 30 meters for the *x* and *y* axis and 1 meter for the elevation was used, all the FBSs towers were 8 meters high and the MSs height were set at 1.2 meters. The frequency used was 900 MHz, which is a very commonly used frequency for GSM systems and the MS transmit power was set at 2 watts, which is a common maximum level power for GSM mobile devices.

4.4.1.1 Antennas

To simplify the simulation, an isotropic antenna was used for the MS. The isotropic antenna is an ideal antenna that radiates its power uniformly in all directions and does not exist in the real world, but since MSs in the real world would use very complicated antennas, with many elements and lobes, and can change its orientation all the time, the isotropic is a good approximation.

Figure 4.7 - ½ wave dipole radiation pattern

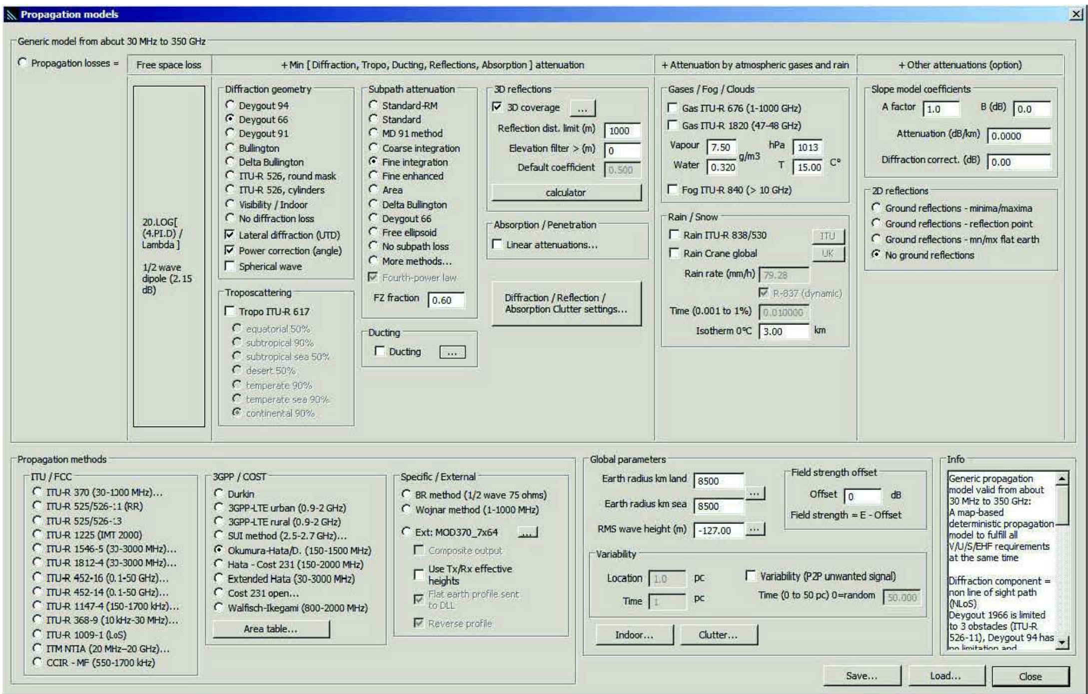


For the FBSs, a ½ wave dipole was used, the ½ wave dipole is very common type of antenna that radiates its power equally around its axis (with a gain of 2.15 dB) and does not radiate in the direction of its axis. As its name implies, its length is half of the wavelength of the frequency used, which in this case would be close to 0.17 meters. This antenna was chosen because it is omnidirectional and on the xy plane, which means that it receives the signal with the same gain from all directions as long as long as the elevation of the MS is the same, its lobe is also wide enough that a small change in the MS elevation caused by variations of the terrain, don't have a big effect on the effective gain.

4.4.1.2 Okumura-Hata propagation model

Also known as the Hata model, the Okumura-Hata propagation model was developed in the 1980s for predicting path loss of cellular communications in urban, suburban and rural environments, it was based on the Okumura model developed in 1968 and can be applied to frequencies between 150 and 1500 MHz and mobile stations ranging from 1 to 10 meters of height. But since the Okumura-Hata model presupposes a base antenna height of at least 30 meters, the subpath loss through fine integration with an FZ fraction (fraction of the Fresnel ellipsoid that must be cleared to avoid substantial subpath loss) of 0.6 was added and specular 3D reflections were also checked.

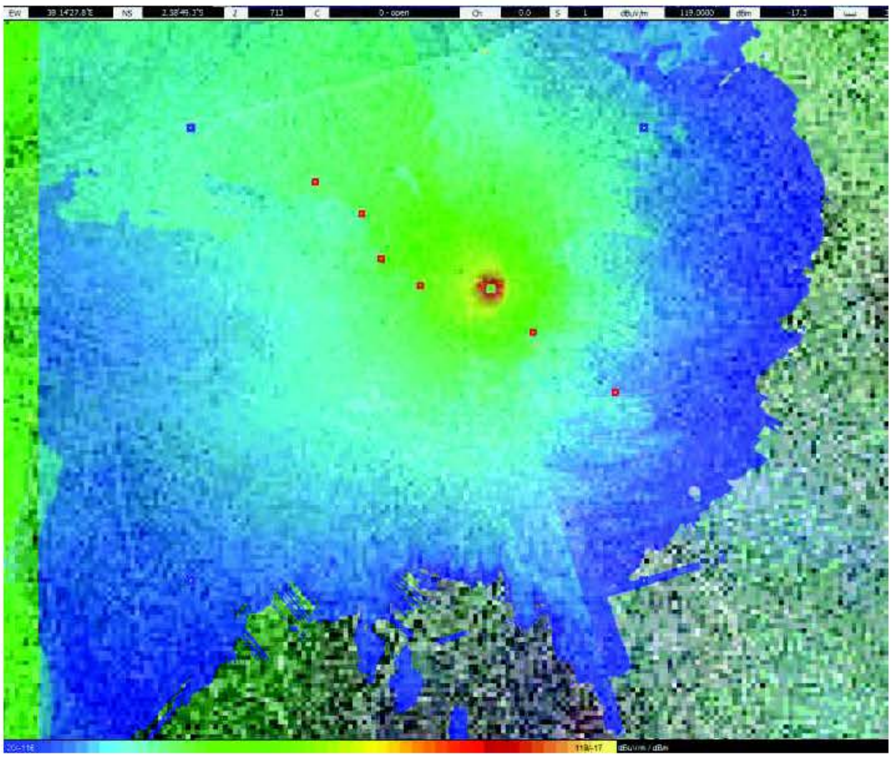
Figure 4.8 - Parameters used for the simulations



4.4.2 - RSS Based Localization

To estimate the location of the mobile station based on the Received Signal Strength (RSS), the signal from the Mobile Station (MS) reaching each of the FBSs is calculated by the simulator in dBm, then it is converted to Watt and, in the cases where the signal is strong enough to be captured by an FBS, d_0 is calculated using equation (2) and depending on its value, the FBS-MS distance is determined using equation (7) or (8) as explained on chapter 2. Figure 4.9 presents the screen shown by the simulator for one of the MS locations, the green dot is the MS and the blue dots are the FBSs.

Figure 4.9 - RSS coverage simulation

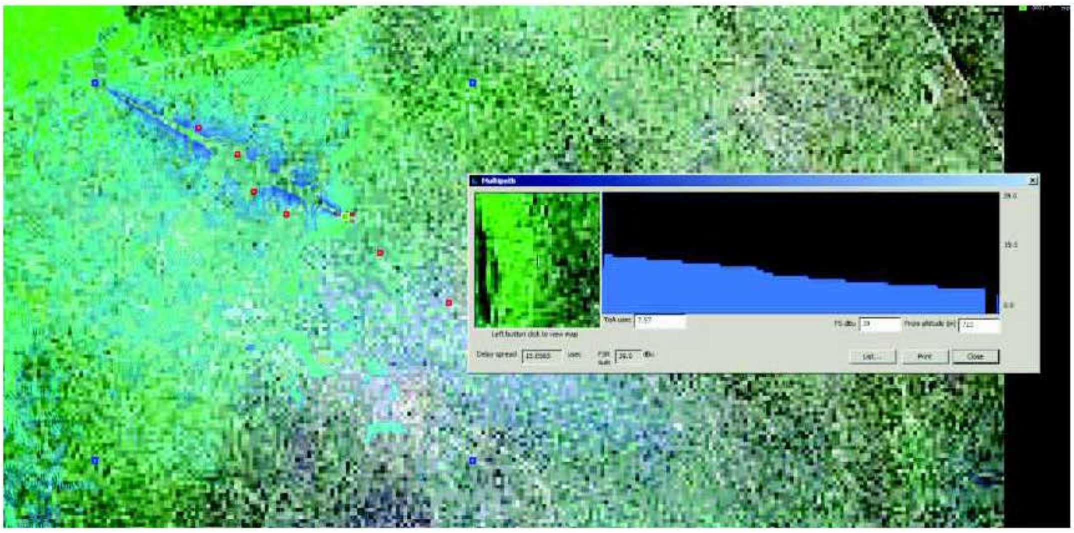


4.4.3 - TOA Based Localization

To estimate the location of the mobile station based on the Time of Arrival (TOA), the "multipath delay spread" function of the simulator is used to determine the time it takes the first wave from the MS to reach the FBS with enough energy to be sensed by its radio. Then, using equation (13) shown in chapter 2, the FBS-MS distance is determined based on the time measured.

Figure 4.10 presents the screen shown by the simulator for one the MS locations, the green dot is the MS and the blue dot on the top-left is the FBS used for this measurement. The box on the right shows the spread of TOAs of the signals reaching the FBS from the MS, it also shows the signal strength of the signals at each time. That time is measured with an accuracy of one hundredth of a microsecond, which translates to a 3 meters resolution.

Figure 4.10 - TOA measurement (multipath delay spread)

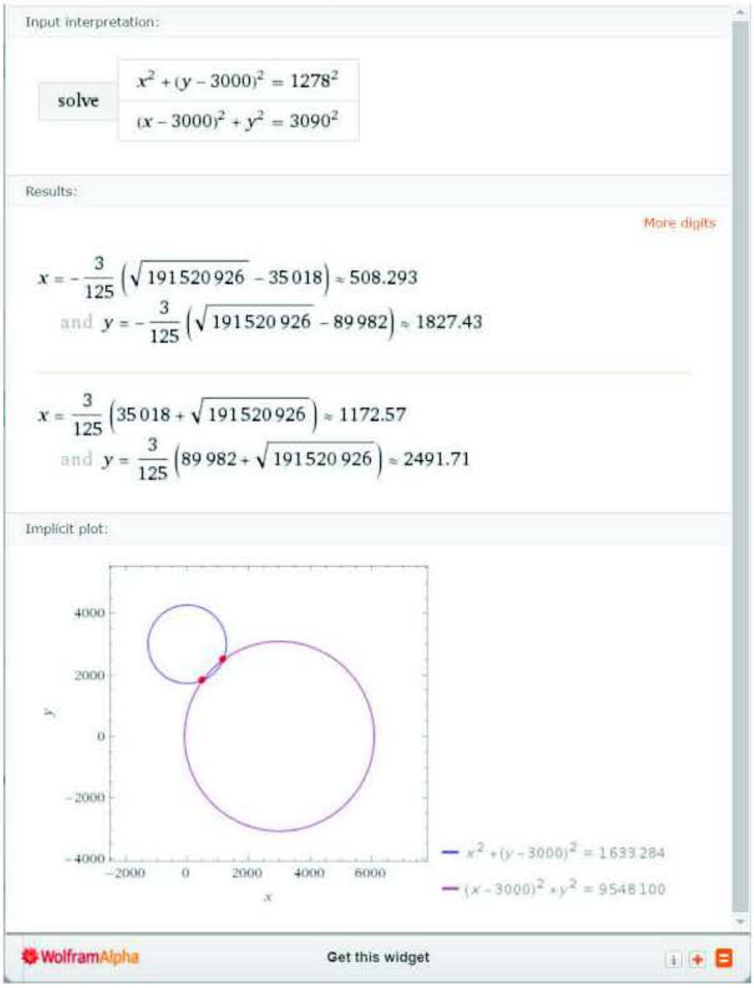


4.4.4 - Calculating the location based on the distances measured

After estimating the distances from the MS to the FBSs, those measurements can be used to determine the MS location. There are four FBSs around the MS, but its signal doesn't always get to all FBSs with enough strength to be measured by the FBS radio, so in some cases there are four good measurements, but in others there are only three or, in the worst case found in this study, only two good ones.

In the points where only three good measurements are found, equation system (11) discussed in chapter 2, can be used directly to find the location and the results that point outside of the square formed by the four FBSs are ignored.

Figure 4.11 - Wolfram Alpha System of Equations Solver



In the points where there are four good measurements, as in the previous case, equation system (12) is used. In this system there is one equation for each FBS, and three equations with three variables, but our problem has four measurements from four different

FBSs. If they were to be used all at the same time, in a system of four equations, because those measurements contain an error, a contradicting system would be created and a solution would not be possible. So, they are used 3 at a time instead, and four locations are calculated with the different combinations of those measurements, and then the location of the MS is estimated as a point between these four points.

In the points where only two good measurements are found, equation system (11) is used directly to find the location, but only two of those equations are used, then two results are found and it can be estimated that the MS is in one those points, but there is not enough information to determine which one is the real location of the MS.

To help solve those systems, the Wolfram Alpha System of Equations Solver [20] was used. Wolfram Alpha is a computational knowledge engine available online and developed by Wolfram Research.

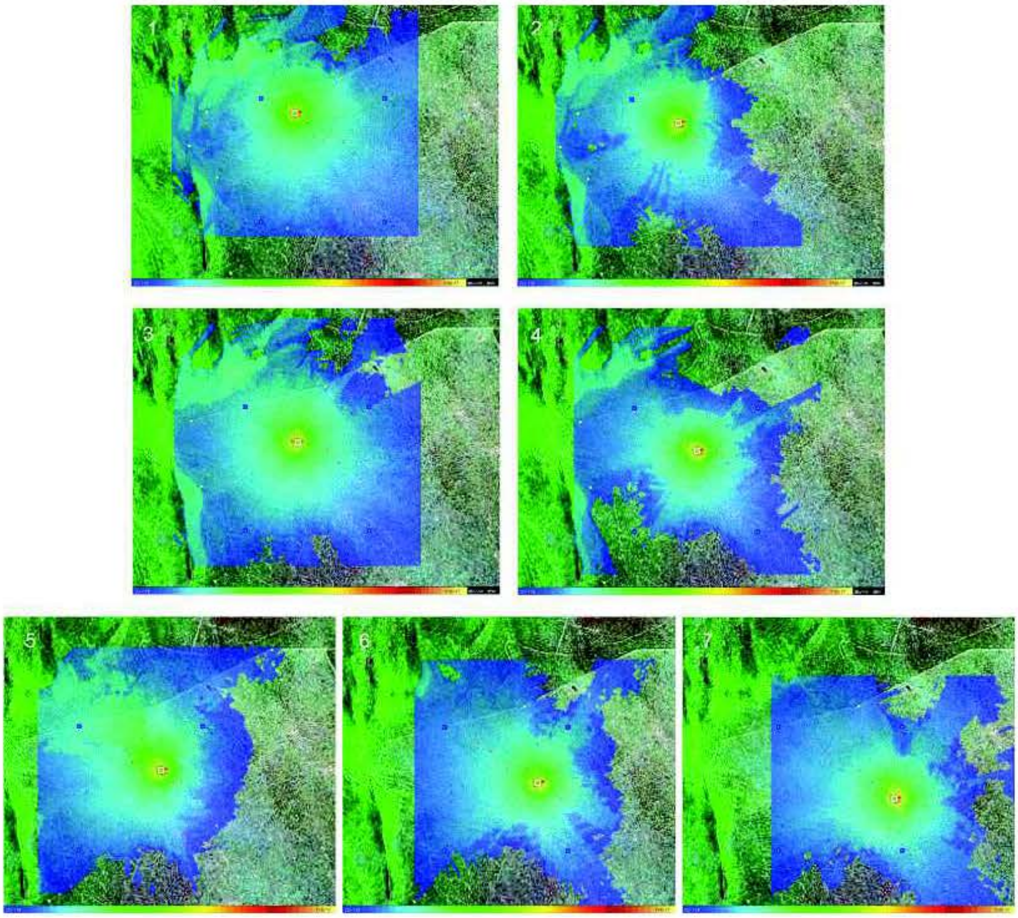
5 EXPERIMENTAL RESULTS

In this chapter, the results from the experiments described in chapter 4 are presented and discussed, followed by a discussion on those results and other possibilities of implementation.

5.1 Results Presentation

Figure 5.1 shows the signal strength plotted by the simulator for all the points in the experiment, which demonstrate that most of the points provide a signal strong enough for all four FBSs to perform a measurement. Only points 2 and 4 have trouble reaching all FBSs, with point 4 missing one FBS, which means that there are still three measurements and a location can still be determined.

Figure 5.1 - Coverage simulation on all 7 points



Point 2 presents a bit of a challenge, because it missed two FBSs, which means there are only two measurements and by the intersection of the distances determined with those measurements, two possible locations for the MS can be estimated, but there isn't enough information to determine which of the two is the real location unless the system considers a previous measurement and determines that the real location is the one closer to where the MS was before.

Table 5.1 - RSS and TOA localization results

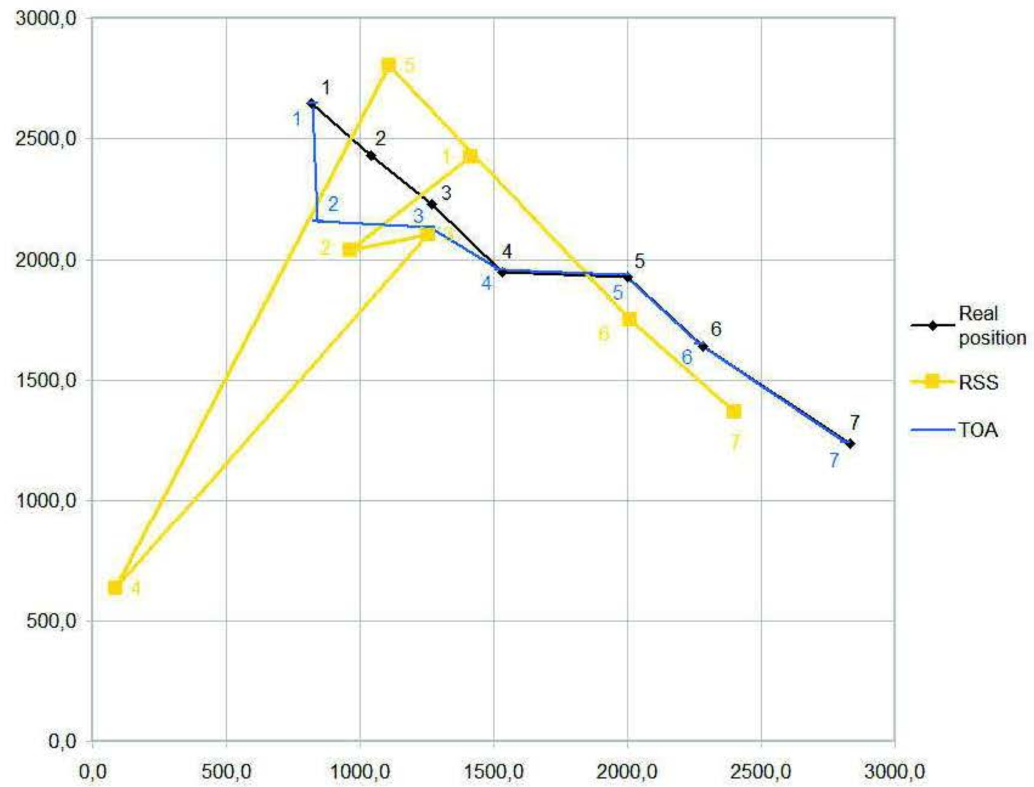
	Real Position		RSS			TOA		
	x (m)	y (m)	x (m)	y (m)	error (m)	x (m)	y (m)	error (m)
1	820	2650	1415.0	2425.8	635.85	820.9	2647.2	2.90
2	1040	2430	963.5	2036.5	400.87	840.4	2159.6	336.11
3	1270	2230	1254.5	2103.1	127.89	1260.3	2134.5	95.99
4	1530	1950	87.9	634.3	1952.11	1521.8	1956.6	10.53
5	2000	1930	1108.4	2803.8	1248.34	1984.6	1938.3	17.52
6	2280	1640	2009.6	1749.7	291.84	2266.6	1648.9	16.08
7	2830	1240	2401.0	1367.3	447.51	2815.7	1245.2	15.27

Table 5.1 shows the results using both Time of Arrival (TOA) and Received Signal Strength (RSS) measurements and their respective errors, in this case, the error is the distance in meters between the real position and the estimated one. In all cases the TOA method was much more accurate and the only case where it had an error close to the one observed on the RSS experiment was in point number 2, and it was because only the measurements from two of the four FBSs were strong enough to be considered as was discussed above.

For the RSS methods, the best measurement had an error of more than 100 meters and the worse was close to 2000 meters, while most were around 500 meters, which suggests that when using RSS measurements for localization, some form of fingerprinting technique must be used to give an acceptable result.

Figure 5.1 shows the same results from the table above, in a graph where the real positions of the MS are plotted in black, the locations obtained from the RSS measurements are plotted in yellow and the locations obtained from TOA measurements are plotted in blue. The four FBSs are located in the four corners of this graph.

Figure 5.2 - Localization results



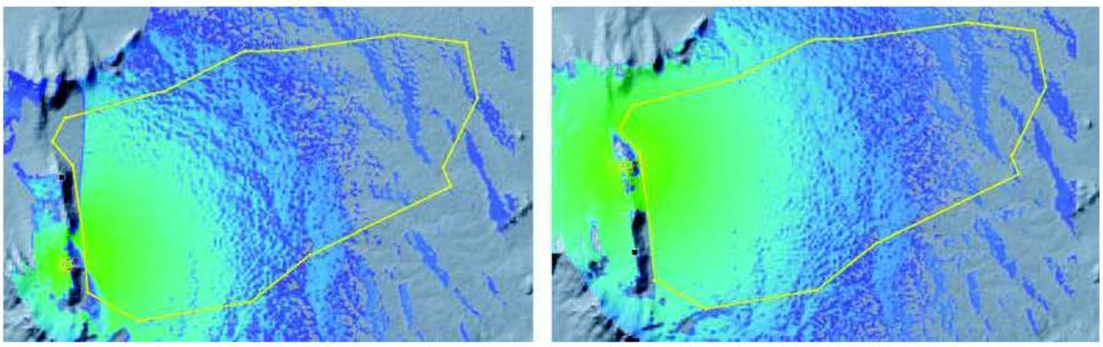
5.2 Discussion

From the results of the experiments, it is clear that in this scenario, the TOA method for localization is a lot more effective than the RSS method and provided very good precision, so, it should be used whenever possible. RSS on the other hand, wasn't very precise because when the antennas are so close to the ground, distance is not the determining factor to signal strength and even some change in the ground elevation between the FBS and the MS can cause substantial changes to those measurements. Therefore, when RSS is the only method available for localization, it is recommended that it is combined with some form of fingerprinting technique.

In those experiments, a network of FBSs three kilometers apart was able to provide good coverage in most areas when using the TOA method, and since this scenario has a reasonably flat terrain and few sources of signal reflection and blocking between the FBS and the MS, it was observed that multipath was not a big concern, since reflected signals were arriving with much lower strength than the direct one.

Another interesting solution that would require much less resources to be implemented, would be to install two stations close to the Ngulia Hills, one at each side separated by a reasonable distance and preferably close to the border of the plains where the Ngulia Lodge is situated. Since those plains offer a good unobstructed view elevated close to 200 meters over the sanctuary, FBSs there would provide much better range than on the ground, and since in this case it's only necessary to capture signals coming from the sanctuary, more directional antennas could be used to improve range. Figure 5.3 shows that such a configuration would be able to cover close to half of the sanctuary.

Figure 5.3 - Coverage of 2 stations located close to the Ngulia Lodge



6 CONCLUSION

This thesis aims to compare the use of TOA and RSS localization methods and evaluate the feasibility and accuracy of a system using those methods in the african savannah using the ICS Telecom simulator. This system could be used to unobtrusively locate poachers or missing persons that were carrying a GSM phone in the african savannah. Poaching of rhinos and elephants has been escalating in the last decades in Africa, mostly for their horns and ivory tusks and of a population that was once close to one million animals, today only 20,000 white rhinos and less than 5,000 black rhinos remain. It is very important to develop technology to help the rangers who fight those crimes, because while in some places the poachers even use helicopters, the rangers have very little equipment and in some cases a pair of binoculars is their only location tool.

To perform this evaluation, which were done considering the Ngulia Rhino Sanctuary in Kenya as the scenario, a series of experiments were made. First, a distance between FBSs were set considering both the amount of stations that would be necessary to cover the sanctuary and the range of each station. Then, several measurements were taken in the simulator, with a mobile station (MS) in different positions to emulate the movement of a person carrying a GSM device and four FBSs at each corner. Those measurements were the signal strength and the time of arrival at each FBS for each position of the MS, and based on those measurements, the location of the MS was estimated.

With a distance between FBSs of three kilometers, it was determined that 13 stations would be needed to cover the sanctuary, and using that distance, the experiments showed that the TOA method provide much better accuracy than the RSS method. While RSS localization never provided an error smaller 100 meters, using TOA the measurements were less than 20 meters distant from the real position in most cases, which would be enough for the needs of the rangers in the african savannah.

There are still a lot of related areas for future research, an interesting option would be to evaluate what kind of infrastructure there is at the Ngulia Rhino Sanctuary, things like towers and stations, and estimate the effectiveness of a network using those places for the FBSs. Another interesting case would be to study how far a set of stations at the Ngulia

Lodge, which is close to 200 meters above the sanctuary, would reach. Or even using some antennas at the Ngulia Hills which are even higher with an elevation of 400 meters over the sanctuary.

Other potentially useful study would be to experiment with a set of directional antennas at each FBS, like the ones used in commercial BTSs, to increase the range of the FBS and also to determine best locations on the map for the FBSs to optimize the coverage area. It would also test with an hexagonal antenna arrangement to have a better coverage and with other propagation models. Finally, it is important to experiment with real systems to validate the data and the propagation model used before implementing a physical network.

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