Efficient Radio Resource Allocation in a GSM and GPRS Cellular Network

David E Vannucci & Peter J Chitamu
Centre for Telecommunications Access and Services*
School of Electrical and Information Engineering
University of the Witwatersrand, Johannesburg, South Africa
{d.vannucci, p.chitamu}@ee.wits.ac.za

***Abstract*— This paper investigates the effect of various radio resource allocation strategies in a GSM/GPRS cellular network. The most efficient resource allocation is analysed as a function of the proportion of circuit switched voice and packet switched data load. The Grade of Service and average packet delay is investigated as a function of the load, packet size and call duration. Additionally, the feasibility of using voice over Internet Protocol as opposed to circuit switched voice is investigated as a means to increase subscriber capacity per base station. The work is motivated firstly by the complexity of having both circuit switched and packet switched connectivity on GSM/GPRS mobile cellular system and secondly that an exclusively packet based access on GSM/GPRS has the potential to increase the efficiency of resource utilisation by suitably varying the channel allocation to exploit the characteristics of voice and data traffic.**

***Index Terms*— Resource Allocation, VoIP, GPRS, GSM.**

I. INTRODUCTION

CURRENT wireless personal communication systems are increasingly serving the demands of both voice, data and multimedia users. Previously these services were considered separate and the network was optimised for either voice or data services. With the advent of multimedia services, it is now clear that networks must support an integration of both, according to local requirements.

It is for this reason that the GSM system has been extended by the General Packet Radio Service (GPRS). GPRS is a packet switching service developed for GSM to facilitate user access to IP based services by dynamically allocating bandwidth to users [1],[4].

In South Africa the situation is as follows:

- There is a low penetration of wireline telephone services to homes, the mean teledensity is 12%, decreasing to less than 5% in small towns and rural areas.
- As of December 2003 there were more mobile subscribers compared to wireline subscribers, with an estimated mobile market penetration of over 30% [3].

It is likely that wireless based solutions in various forms, such as Wireless LAN, Broadband Wireless Local Loop, and cellular mobile technologies like GSM/GPRS and Universal Mobile Telephony System (UMTS) will play an important role as a technology platform of choice.

*The Centre is supported by Telkom South Africa Limited, Siemens Telecommunications and the THRIP Programme of the South African Department of Trade and Industry.

To address the immediate requirements for voice and data in South Africa we see GPRS as the most likely candidate due to its steady adoption by the mobile operators and the fact that it provides a multi service environment using packet switching. In response to this opportunity, the three local cellular operators have or are in the process of introducing GPRS on their GSM networks.

The use of a radio access network such as GSM/GPRS to provide services in a multi-service environment has many advantages compared to a wired last mile. The key advantage is in the flexibility to provide adequate resources on demand for different mixes of capacity and coverage requirements. The radio access point can be equipped with a range of medium access control strategies to cater for both contention and non-contention access as well as a combination of different multiple access and duplexing techniques to meet different service requirements.

Since GSM and GPRS use the same radio resources for both voice and data services, a number of questions arise regarding how to optimally allocate radio resources under differing traffic mixes for the two services. We expect the narrowband data traffic to be about 10% to 20% of the total load on a GSM/GPRS network. In the GSM network, High Speed Circuit Switched Data (HSCSD) makes it possible to offer data services over circuit switched channels, thus there are a number of possible combinations for voice and data resource allocation:

1) Circuit switched voice and circuit switched data represented by GSM and HSCSD.
2) Circuit switched voice and packet switched data represented by GSM and GPRS
3) Packet switched voice and packet switched data represented by Voice over IP (VoIP) over GPRS.

Up to now there has not been keen interest in GSM/HSCSD (due to the cost of circuit switched data), and therefore we will investigate the traffic model and performance of GSM/GPRS and VoIP over GPRS for a different mix of voice and data traffic loads.

The regulatory framework in many countries is changing. The recent liberalisation to allow voice bearers on traditional data networks has added a new impetus to investigate VoIP over GPRS. VoIP has the potential to provide universal access in a number of markets acting as an enabler of a completely muti-service environment. Fixed line operators are positioning

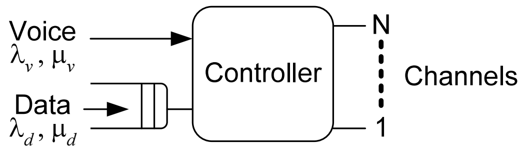

Fig. 1. GSM/GPRS Model

VoIP as an enabler of innovative business and consumer applications [2], with the potential to create new revenue streams.

In this context, operators can decide to temporarily or permanently allocate GSM resources for GPRS. GSM slots permanently allocated to GPRS are called fixed Packet Data Channels (PDCHs), whilst temporarily allocated slots are called on-demand PDCHs [5].

II. SYSTEM MODEL

For our investigation of the GSM/GPRS system, we assume that there are N_V channels available for GSM circuit switched voice and N_D channels available for GPRS packet switched data. Voice and Data arrivals are assumed to be uniformly distributed amongst the respective available resources. We assume that circuit switched voice traffic is generated with a random, Poisson rate λ_V and have a fixed call duration of two minutes. In addition data terminals generate data bursts at a rate of λ_D and the packet length is assumed to be exponentially distributed. The data burst arrival rate is assumed to be the superposition of newly arriving and retransmitted data bursts as in [6].

A. Circuit voice and Packet data

For our model of the GSM operation it was assumed that when a voice call arrives and no resources are available, the call is discarded. For the GPRS resources if a data packet arrives and no resources are available, it is queued in a buffer until it may be serviced. The system model can thus be drawn as shown in figure 1. This system model may be described by the state diagram shown in figure 2.

Let $P_{i,j}$ (i=0,1,2,…,N; j=0,1,2,…) be the steady state probability that there are i voice calls and j data packets in the system. With a Poisson arrival rate and deterministic service time assumptions noted above, it is apparent that transitions follow the pattern shown in figure 2 with the transition rate parameters indicated. Thus transitions out of state $P_{0,0}$ (the empty state) can occur at rate λ_1 or λ_2, whichever arrives first, a voice call or data packet. If the system is in state $i = N_v$, any further voice calls are blocked due to a lack of available resources.

For our GSM/GPRS simulator the two main measures of performance are the probability of a voice call arrival being blocked, and the average delay data packets experience while waiting for service.

The probability of a voice call arriving and being blocked due to insufficient resources is given by the Erlang B formula, as shown in equation 1, where the offered traffic, A, is

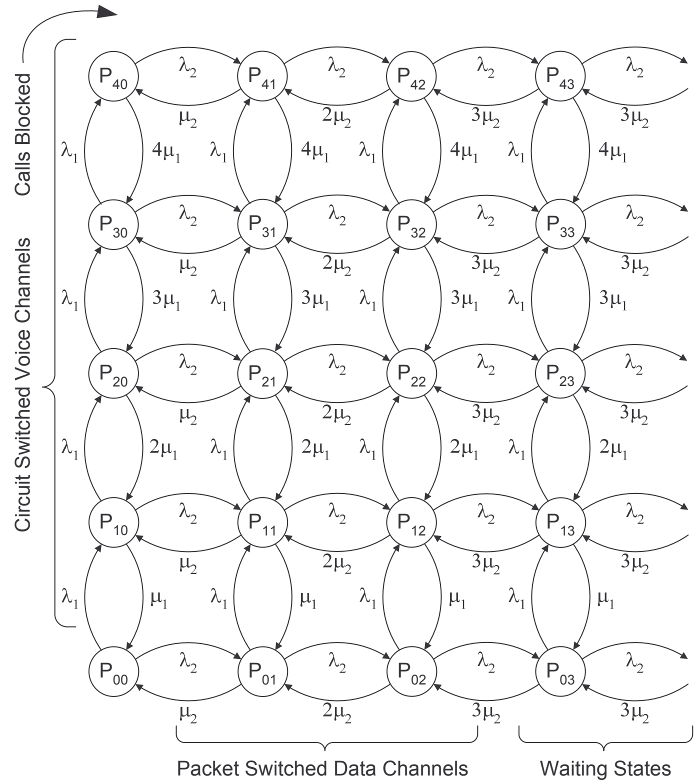

Fig. 2. GSM/GPRS State Diagram

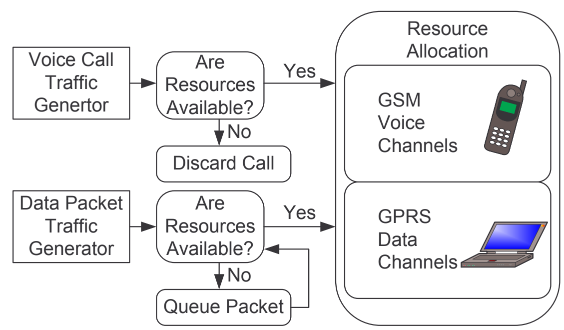

Fig. 3. Radio Resource Algorithm as implemented in the simulator

the number of arrivals per second multiplied by the average holding time per arrival [7]. We assumed an average holding time per call of two minutes. The probability of a data packet being delayed is given by the Erlang C formula, as shown in equation 2 [7].

$$\Pr[\text{Blocking}] = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} \tag{1}$$

$$\Pr[\text{Delay} > 0] = \frac{A^C}{A^C + C!\left(1 - \frac{A}{C}\right) \sum_{k=0}^{C-1} \frac{A^k}{k!}} \tag{2}$$

The basic implementation of the algorithm model in a simulator is shown in figure 3.

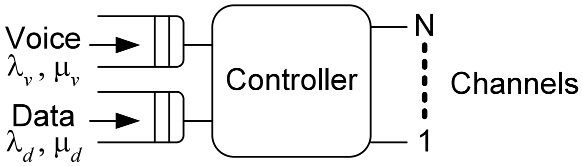

Fig. 4. VoIP GPRS model

GPRS also allows dynamic allocation of resources. Dynamic resource allocation allows unused voice channel resources to be allocated to data on a temporary basis, with preemptive priority being given to voice. An arriving voice call finding all N_v channels occupied will preempt a data packet if one is receiving service. The packet will then be queued waiting in a First-In-First-Out manner for resources to become available to complete its service. Thus voice calls would still receive the same level of service as before, described by the Erlang B formula. The probability of a packet being delayed depends on the probability that all the channels are busy and the probability of preemption during data communication. An iterative simulation is used to solve for the blocking and average delay for this case.

B. Packet Voice and Packet Data

In this scenario it is assumed that all resources are reserved for GPRS use. If voice is transmitted over IP then both the voice and the data are buffered and the system model can be represented as in figure 4.

If we assume that VoIP packets are queued when no resources are available then the state diagram can be thought of as in figure 2, but queueing is allowed for voice.

The Erlang C formula gives the average delay for the data packets. The probability that the delayed packet is forced to wait more than t seconds is given by the probability that a packet is delayed, multiplied by the conditional probability that the delay is greater than t seconds [8]. The system delay probability is given by equation 3 [9], where H is the duration of the packet.

$$\Pr[\text{Delay} > \text{t}] = \Pr[\text{Delay} > 0]e^{-\frac{(C-A)}{H}t} \quad (3)$$

III. NUMERICAL RESULTS AND DISCUSSIONS

The main interest is to establish patterns as parameters change in our investigation. Parameters considered included:

- Voice traffic load
  - Voice Arrival Rate
- Data traffic load
  - Packet Arrival Rate
  - Packet Size
- Resource Allocation for different voice and data mixes
  - Number of voice channels
  - Number of data channels

An average data rate of 12Kbps per slot was assumed for GPRS. As in section II-A we initially investigated the effect of reserving resources for GPRS traffic. The resources available were normalised to one GSM carrier (8-time slots). In the results below N_V represents the number of channels reserved for voice and N_D the number of channels reserved for data.

A. Circuit Voice and Packet Data

The data load was initially set at one Erlang of traffic, and increased to three Erlang, while the GSM circuit switched voice was varied from zero Erlang to a point where the average delay of a packet was two seconds (since the GSM voice calls are given priority the probability of a call being blocked is just given by the Erlang B formula). A number of interesting observations can be made from the simulation output.

a) When there are insufficient resources the delay is similar regardless of packet size: Three packet sizes for the data were considered for this experiment, 100 Byte, 200 Byte and 300 Byte as these were considered to give an indication of smaller, medium and larger bandwidth requirements of various applications. One Erlang of data traffic was applied with no channels being reserved for the data, but a moveable boundary being implemented. As can be seen from figure 5 the average delay is similar for all three packet sizes. This was also found to be the case for a data load of two Erlang as in figure 6.

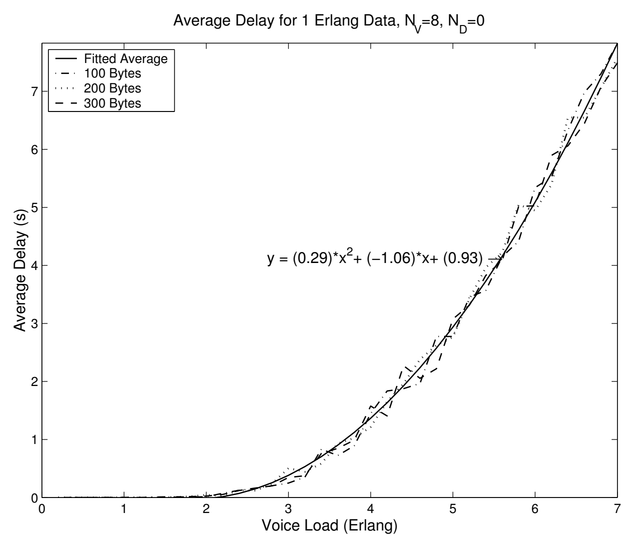

Fig. 5. Average Delay of Various Packet Sizes with 1 Erlang Data load and no fixed resources.

b) The number of data channels should equal the offered load: If the number of data channels is equal to the offered data load the average delay can be expected to be less than 500ms. In figure 7 the average delay for 100, 200 and 300 Byte packets are plotted for the case of no channels reserved for the data and, for one channel reserved for the data – the delay in the case of sufficient resources is roughly one order of magnitude less than that of the case with congestion.

c) With sufficient resources delay increases gradually with increasing packet size: An investigation was done on the effect of packet size for the case when there is sufficient resources for the data. Packets of size 100 to 450 Bytes were simulated. From figure 9 one can see the average delay

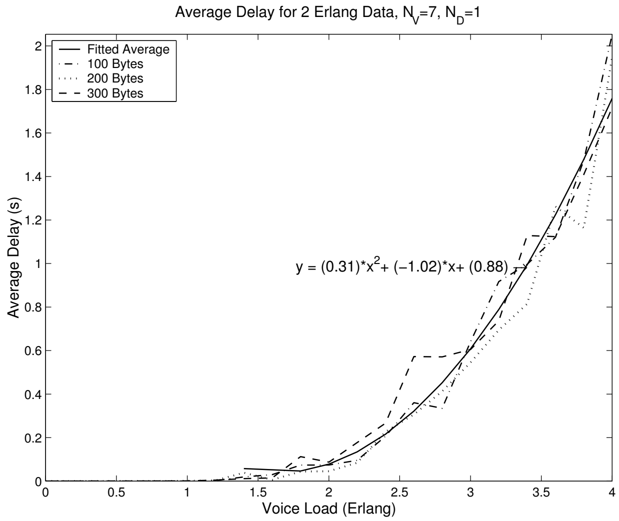

Fig. 6. Average Delay of Various Packet Sizes with 2 Erlang Data load and $N_V = 7, N_D = 1$.

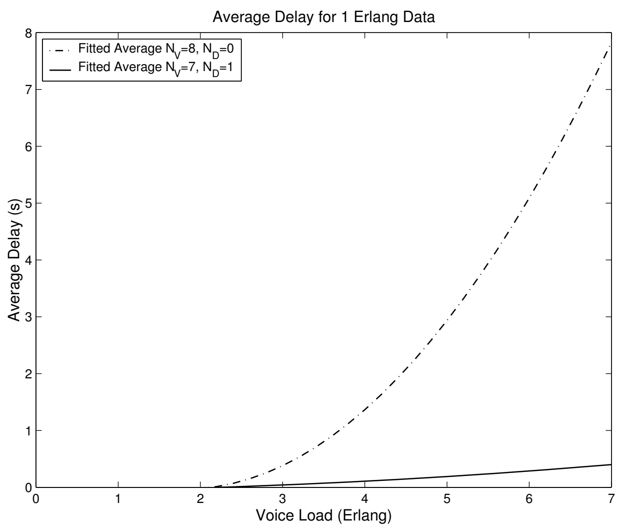

Fig. 7. Average Delay versus Number of Channels reserved for Data.

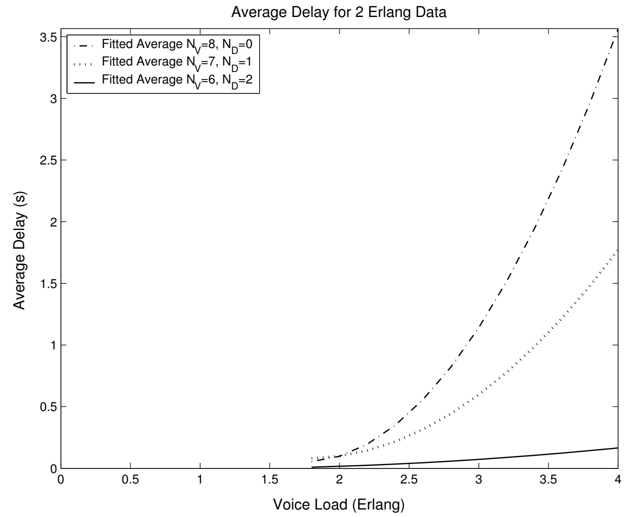

Fig. 8. Average Delay versus Number of Channels reserved for Data.

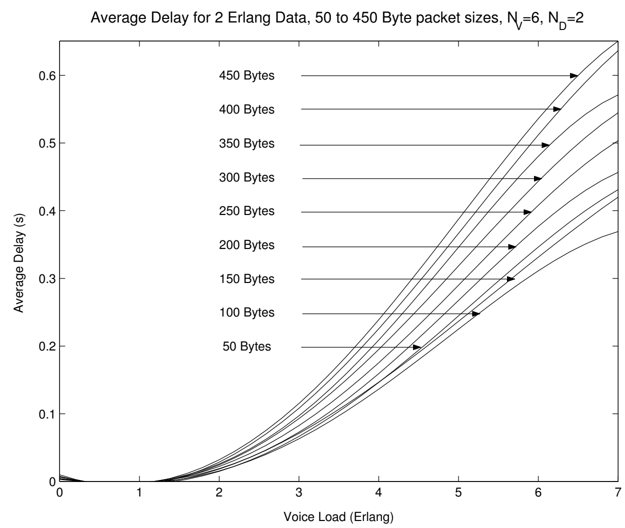

Fig. 9. Average Delay for varying Packet Sizes

increases as packet size increases, with only a minimal change in delay, supporting what one might intuitively expect.

B. Packet Voice and Packet Data

For the case of Voice over IP and normal data traffic two investigations were carried out. Firstly to investigate the effect of changing data packet size with VoIP traffic and secondly to determine the maximum VoIP load for a given data packet size.

d) VoIP delay increases sharply when the total offered load is greater than seven Erlang: The data traffic load was varied from zero to seven Erlang for VoIP loads of one to six Erlang. A fixed packet size of 150 Bytes was used for this simulation. From figure 10 one can see the point of increase in VoIP packet delay occurs when the sum of the VoIP load and data load starts to exceed seven Erlang.

e) Data packet delay increases sharply when the total offered load is greater than seven Erlang: For this simulation the VoIP load was varied from one to six Erlang for various data packet sizes as shown in figure 11. The data load was fixed at two Erlang. As before when the total load started to exceed seven Erlang, the delay for the packets increased rapidly.

f) Packet multiplexing of VoIP traffic and data traffic allows more effective use of the air interface: With a circuit switched voice load of three Erlang, referring to figure 6, the average data packet delay for two Erlang of data is 600 ms. Alternatively with VoIP the packet delay is roughly one sixth, as shown in figure 9. Thus by comparing the case of circuit switched voice and packet switched data one can conclude that the benefits of multiplexing allow greater data traffic load to be supported under equivalent voice traffic load.

IV. CONCLUSIONS

This paper has considered different resource allocations which can be used in GSM/GPRS cellular networks for different combinations of voice and data load. The significance of

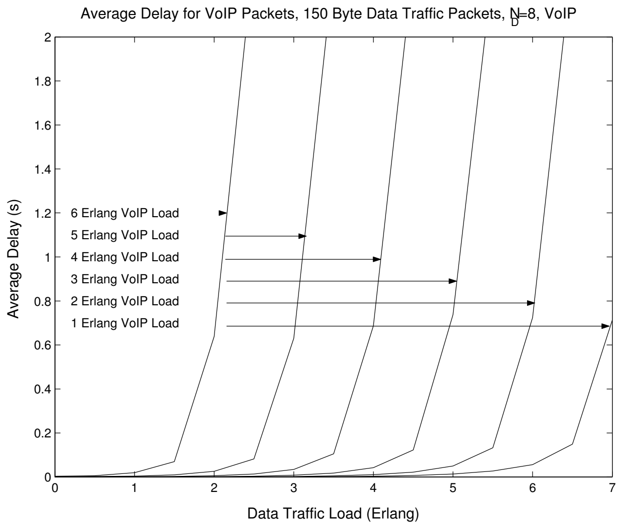

Fig. 10. Average Delay for Varying Packet Size, with sufficient resources for Data.

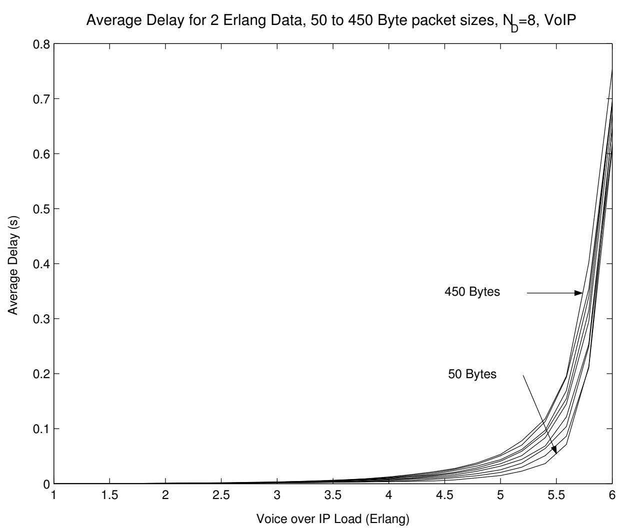

Fig. 11. Average Delay for Varying Packet Size, with sufficient resources for Data.

this study should be seen in view of mobile phone penetration and the market drive for wireless data services, in South Africa in particular, and around the world in general. The complete set of results we explored were: circuit switched voice and packet switched data with static and dynamic resource allocation, and packetised voice in the form of VoIP and data with prioritisation for the VoIP packets. From the observed patterns linking the available radio resources and allocations for different traffic mixes several key conclusions can be reached: When the fixed PDCH resources for GPRS are less than the offered data load the delay is similar regardless of the packet size. Simulation has shown that it is unnecessary for fixed PDCHs to exceed the offered load, and with sufficient resources the delay increases gradually with packet size. For the case of all resources being reserved for GPRS and VoIP being used, it was found that the VoIP load and data load should not exceed seven Erlang for a maximum radio resource of eight channels. As expected packet multiplexing allows more effective use of the air interface, providing a potential for greater base station capacity when using VoIP. Using all resources for GPRS would also facilitate the transition to an all IP network, and provide a further intermediate step to a third generation network.

References

[1] A. Kennedy, J. Mellor, and K. Al-Begain, "Investigation of partitioning strategies for GPRS over GSM networks," PostGraduate Network, 2001, http://www.cms.livjm.ac.uk/ pgnet2001/papers/akennedy.doc.

[2] G. Letts and A. Poon, "VoIP Services in Asia-Pacific Ride the Convergent Path", Yankee Group, 2003, Report No. YG-8574.

[3] International Telecommunications Union, "World Telecommunication Indicators", December 2003, ITU.

[4] B.H. Walke, Mobile Radio Networks - Networking, Protocols and Traffic Performance, 2nd ed., John Wiley and Sons, New York, USA, 2002.

[5] U. Fornefeld, P. Stuckman, A. Bayo, and R. Critelli, " Analysis of the Influence of Packet-data and voice Traffic on the Interference Situation in Multi-cellular GSM / (E)GPRS Networks." Aachen University of Technology.

[6] J.W. So, and D.H. Cho, "Access Scheme for Integrated Voice/Data Transmissions over Common Packet Channel in 3GPP." IEEE communication Letters, Vol.5 No.2, February 2001.

[7] M. Schwartz, Telecommunication Networks: Protocol, Modelling and Analysis, Addison-Wesley 1987,pp.664-698

[8] P. Chitamu and D. Vannucci, "Networking Africa: A Case for VoIP." Proceedings of IEEE Africon 2002. Vol. 1, pp.361-366, Oct 2002.

[9] T. S. Rappaport, Wireless Communications: principles & Practice, Prentice-Hall, 1996, pp. 48.