Peer-to-Peer Wireless Networking for Rural Telecommunications

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Abstract: The general networking connectivity topologies are based on either the client-server (central switching) or Peer-to-Peer (distributed switching) topologies. The determining factor for either central or distributed switching is the aggregate traffic generated by the "clients" per unit area such as Erlang per square area.

The challenge is to determine the appropriate network topologies given customers profiles. We present the concept of Peer-to-Peer networking as applied to rural telecommunications highlighting the key research areas of interest as identified by researchers at the CoE Rural Telecommunications.

The final output from this work is expected to be a software design tool(s) that will take into account not only the generated traffic levels but also other requirements for telecommunication service provision in rural areas including social-economic factors such as economic activities, proximity to cities, and nature of telephone usage.

1. Introduction

Telecommunications Service provision in rural areas of developing countries is either inadequate or none existence. This is due to a number of reasons ranging from suitability of networking solutions to high investment and running costs of rural tele-communications infrastructure.

A combination of lack of geographical locations proximity to large population centres and low potential customer densities makes telecommunications service provision in rural areas a little more cumbersome than in urban areas.

The challenge has always been the fact that the rural communities are not naturally aggregated enough as urban populations to enable deployment of high capacity networks.

There are two possible solutions to the customer aggregation problem:

(i) Use of distributed networking technologies such as DaRT that can aggregate traffic over a large geographical area [6].

(ii) Centralized network topologies and services such as the traditional PSTN

In terms of network topologies we refer to the two above as Peer-to-Peer (distributed switching) or client-server (central switching) topologies respectively.

Network topology deals with the manner in which the network elements, nodes and links are interconnected. We review the two topologies used in networking, namely the central and distributed switching distribution [8]. Central switching is more suited to high traffic density areas such as the urban areas.

On the other hand, hand, peer-to-peer or distributed topology is considered to be better suited for low traffic density areas such as the rural areas. Urban areas usually generate high traffic levels per unit area and therefore client-server topology is deployed. The rural areas on the other hand may generate order of 0.2 Erlang per square km which makes it more cost effective to deploy Peer-to-Peer networking topology.

Between these two extremes, one can have a combination of client-server and Peer-to-Peer networking to optimise on the overall costs of service provisioning. This can take the form of inter-connected low capacity switches.

The main objectives in network planning is to optimise costs between switching, distribution, and transmission. Client-server topologies tend to have the highest costs on switching equipment while Peer-to-Peer networks have the costs mainly on access and distribution (routing). These are some of the assumptions we set out to validate.

The rule of thumb for selection of technology and associated connectivity topology is depicted in Table 1. [2,3]

Table 1 Choice of technology given specific population (traffic) densities

Population Density	LOW			HIGH
Technology	VSAT	WLL	Copper	Fiber

It can be deduced from the table 1 that VSAT should be considered in areas with low population densities. However, the boundaries between the technologies together with the actual traffic levels is a gray area which needs to be quantified. Our study intends to quantify the boundaries of suitable technologies and inter-connection topologies based on mainly the traffic levels. However, the challenge in rural telecommunications remains reaching as many subscribers as possible. We assume that technology choice plays the crucial role but has to be done considering the following issues:

- Demand
- Population Density
- Traffic
- Coverage requirements
- Equipment costs
- Regulatory framework
- Spectrum Availability

Before continuing with our discussion of suitability of peer-to-peer networking for rural areas, we present an overview of SA rural customer profiles. These include data related to household incomes, agricultural products, penetration of power, informal housing, and customer density.

The rest of the paper is organised as follows. Section 2 explains the need for rural telecommunications. An example of traffic modelling for rural Kwazulu Natal is presented in section 3 followed by an overview of technology options in section 4. Section 5 discusses the expected output from the study of Peer-to-Peer networking for rural telecommunications followed by discussions and conclusions in section 6.

2. Why Rural Telecommunications

Two main reasons:

(1) A big proportion of the SA population live in rural areas

(2) There are number of social-economic activities taking place in rural areas

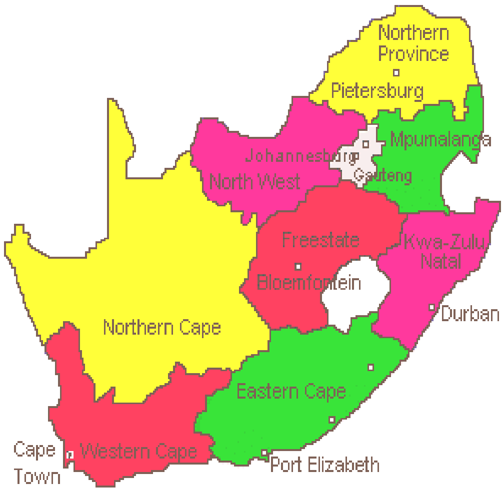

Figure 1 Map of South Africa

The table 2 shows the population of urban and non-urban in different provinces of South Africa. Out of the nine provinces, six have over 50% of the population living in rural areas [5].

Table 2 South African population by province, 1996

	Urban Population	**Non Urban Population**
Eastern Cape	36.6	63.4
Free State	68.6	31.4
Gauteng	97	3
KwaZulu Natal	43.1	56.9
Mpumalanga	39.1	60.9
Northern Cape	70.1	29.9
Northern Province	11	89
North West	34.9	65.1
Western Cape	88.9	11.1

The South African population is distributed evenly between urban and non-urban areas. But this distribution varies by race group. Almost two-thirds (63%) of Africans live in non-urban areas as against a far smaller proportion of coloureds (16%), Indians (5%) and whites (9%).

Annual household incomes vary widely in urban, compared to non-urban, areas. While only 8% of households in urban areas fall into the bottom income quintile, 29% of households in non-urban areas are found in this category. At the upper extreme, 34% of urban households are found in the top income category, compared with only 8% of non-urban households [5].

Households living in urban areas have more than double annual income (R55 000) of those living in non-urban areas (R23 000). However, the total agricultural production, which includes field crop products, animal products, etc. , for 1998 was 53,160,000 tons with the gross value in millions being R39,314 represents significant wealth generated from rural areas.

In terms of housing, about 80% of the population live in formal settlements [5]. This represents the potential for service provision. With regard to electricity and telecommunication service provision in rural areas, the current penetration of telecommunication is approximately 3% as compared to the penetration of electricity, which is 34%. We would therefore expect telecommunication service provision to grow rapidly to about 34% if appropriate network topology for cost effective deployment of telecommunication infrastructure is adopted. This is one of the main motivations for this work.

3. Traffic Modeling for Rural KwazuluNatal

With its population of more than one-fifth (20%) of all the people in the country, KwaZulu-Natal is the most populous province, but occupies only 8% of Republic South Africa's (RSA) land mass. While the vast majority of people in the province (83%) are African, a large proportion of the one million Indians in the country (80%) live here. It is largely rural in character, with 61% of the population living in non-urban areas [5]. The land area of Kwazulu Natal is 97 527 sq. km which is about 8% of RSA of land area 1 219 090 sq.km.

A relatively small proportion of all households in KwaZulu-Natal (12%) are in the bottom income quintile. Instead, incomes tend to cluster into the third (25%) and fourth (24%) quintiles. Both female- and male-headed, non-urban households are relatively well off compared to households in non-urban areas in other provinces, with 22% of female- and 15% of male-headed households being found in the bottom quintile.

3.1 Traffic Estimation

So as to demonstrate the expected traffic levels from rural areas, we compute the estimated traffic for different coverage areas in rural Kwazulu Natal. We are targeting a voice and data service using a tree – structured Wireless Access System which takes the form of a fixed cellular system with LOS Microwave Backhaul from Base Stations to Base Station Controller to enable a wide area coverage in low density rural areas.

We are planning for Rural Radio Service which combines both voice (14.4kbps) and data (64kbps) services:

Voice call rate 0.02 calls/hr, activity 50%, holding time 5 minutes.

Data call rate 0.02 calls/hr, activity 10%, holding time 5 minutes.

Note that 0.02 calls/hr represents approximately 25 minutes of use per person per month.
Total offered load per subscriber:

$$E = 0.02 * 5/60 * 0.5 + 0.02 * 5/60 * 0.1 * 6.4 = 1.9 * 10^{-3} = 0.002 \text{ Erlang}$$

The constant 6.4 is a modulation and multiple access related parameter.

If we divide rural Kwazulu Natal into three service areas based on propagation and terrain features, each service area will have a population of 1 692 667 in an area of 26007 sq.km giving a population density of 65 persons per sq.km. The traffic is correspondingly 0.13 Erlang per sq.km.

The rural population requires a technology that supports low call rate or low traffic areas within a large coverage area. For example, the expected traffic from rural KwaZulu Natal is estimated as follows:

Table 3 Estimated traffic generated from Rural Kwazulu Natal

BS Radio Coverage (Radius) [km]	Coverage Area [km^2]	Total Population [Persons/ sq.km]	Traffic generated [Erlang]	Equivalent number of trunks for P_B of 2%
5	78.54	5 105	10.21	17
7.5	176.72	11 486.45	22.97	31
10	314.16	20 420	40.84	51
15	706.86	45 946	91.89	100

The low figure of traffic per unit area indicates that the rural radio system is range rather than capacity limited. It therefore doesn't matter whether the Wireless Access System is based on TDMA or CDMA multiple access technology provided the system meets the radio range requirements. This is a slightly different consideration from normal cellular system design where the aim is to improve the capacity of the system.

4. Technology Options for Rural Telecommunications

For rural telecommunications, the challenges are in the access, switching and distribution as illustrated in figure 2. Transport can use Microwave, Coaxial Cable, Fiber, or Satellite.

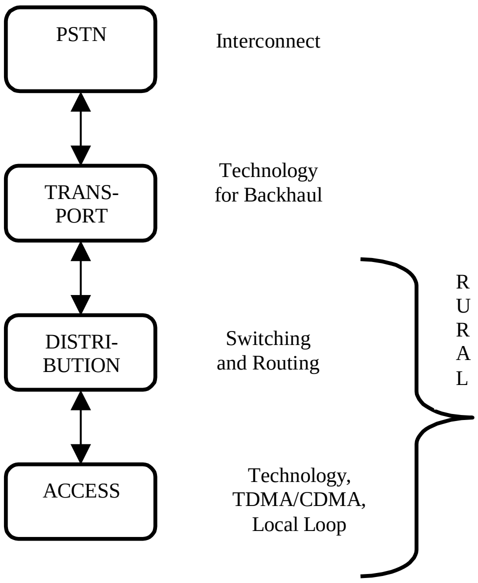

Figure 2 Tree-structured network topology

Some of the technologies which have been considered for rural areas include:

- Wireless Local Loop
- Cellular (IS-95, GSM, etc)
- Point-to-Multi Point Wireless Access
- VSAT
- Cordless (CT2, PHS, Digital European Cordless Telephone (DECT))
- Integrated / Combined VSAT / WLL
- Integrated / Combined Microwave / WLL
- Proprietary Solutions such as DaRT

Potential shortcomings of the above technologies are:

- WLL: Radio range is coverage limited. Unsuitable for low density traffic over large geographical area
- VSAT : suitable for low density traffic. Cost of terminals and per minute service charge is high. If VSAT is used as a backhaul technology, it is suitable for clustered rural areas using integrated VSAT/WLL [3]
- Cordless, DECT: Radio range and coverage limited. Unsuitable for low density traffic, large coverage area
- Proprietary Solutions (e.g. DaRT): Lack of standardisation makes investment insecure. Combination of coverage and capacity limitation is a possibility

In planning a telecommunication network, the objective is to determine the numbers, sizes, locations, and boundaries of exchanges, and the arrangements and quantities of junctions between them, in such a way as to minimise total cost , subject to meeting the stipulated standards of performance (including grade of service, reliability and quality of transmission). This is where the choice of topology plays an important role.

5. Expected Research Output

A generic network can support switching and routing of traffic at different levels of the network hierarchy as shown in figure 3. This work aims to produce a software design tool that will enable evaluation of an appropriate switching level and topology given customer profiles. In particular, we consider the peer-to-peer networking defined in this work as switching and routing at either or both the Customer Peripheral Equipment (CPE) and Base Stations (BS).

The decision metric will also include an economic analysis by costing the various switching and routing options available.

6. Discussion and Conclusion

We have first noted the inadequacy of telecommunication service provision in rural South Africa in general and rural Kwazulu Natal in particular.

This work intends to produce methodologies to determined the appropriate topology given customers profile and the generated traffic per area in particular for rural telecommunication applications.

Given the social-economic activities we note that it can be economically justifiable to provide tele-communication services to rural areas, provided that the networking options and technologies are properly investigated. One networking option available for rural areas is the peer-to-peer networking.

The justification for a Peer-to-Peer topology include:

- more suited to distributed low density traffic and customers which fits the profile of customers in the rural areas
- The cost of the infrastructure is expected to be low due to the low capacity of the Base Stations
- It is possible to match growth in service demand against system capacity roll-out

Lastly, the huge disparity between electrical power provision and telecommunications service provision indicates that there is a huge potential market for rural telecommunication which can possibly grow from present 3% to 34%. However, this will only be possibly if non-traditional and even radical topologies solutions for rural networking is adopted.

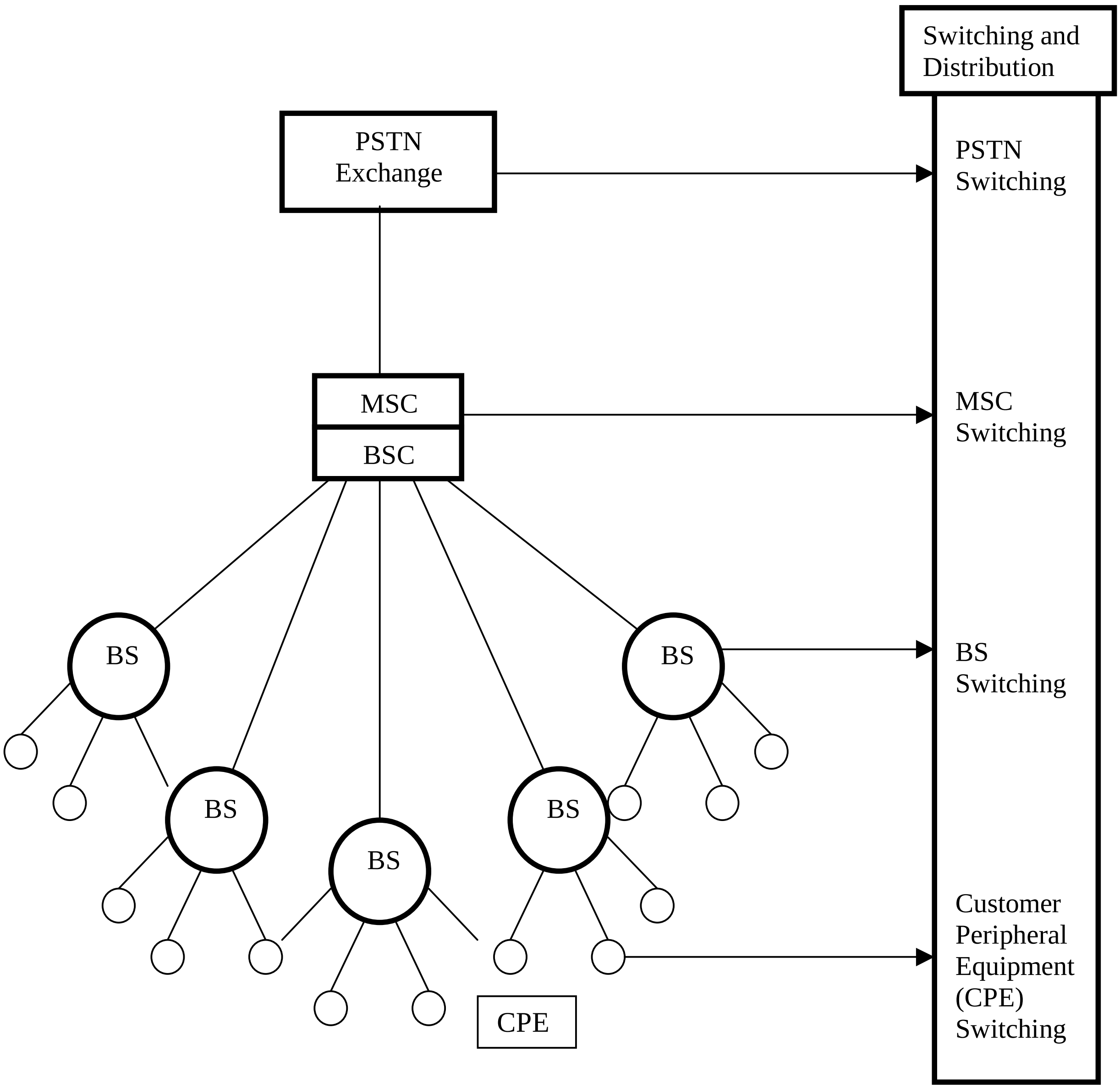

Fig. 3 Possible switching levels in a tree-structured network.

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