Research Proposal

Title: Wireless Mesh Networks: a rural community case

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1. Abstract

Wireless Mesh Network is presented as an appealing solution for bridging the digital divide between developed and under-developed regions. But the planning and deployment of these networks is not just a technical matter, since its success depends on many other factors tied to the region. Although we observe some deployments, to ensure sustainability, there is still a need of concrete design process model and proper network planning approach for rural regions, especially in Sub-Saharan Africa. The main objective of this project is to provide network connectivity from a landline node in a rural region at very low cost and a framework for cost estimation. Deploying such a network aims to sustain local development. To achieve this objective, we define a methodology composed of ten steps, starting by a deep analysis of the region in order to identify relevant constraints and useful applications to sustain local activities and communication. Approach for planning the physical architecture of the network is based on an indoor-outdoor deployment for reducing the overall cost of the network.

2. Introduction

The development of a region depends on not only the circulation of persons but also on the circulation of information. In a world that claims to be a global village, good information traffic is one of the most concerns. Because it enables development of business models, prevention of disasters or diseases, implementation of new learning process and so on. But many rural regions and sometime urban and semi-urban regions in developing countries are still suffering from the lack of connectivity. That hinders the development, resulting in degradation of both social communication and business advances in those regions and the digital divide becomes more and more apparent. As the map of the Internet World Stats can show, African Internet users represent only 7% of the world Internet users[1].

Connecting the rural regions, particularly in developing countries, is a hard task because of many reasons. The first is their location with sometime the lack of proper roads and hostile environment that make them difficult to reach. Another reason is the lack, the deficiency or the instability of infrastructure, mainly power infrastructure; that seriously hinders the deployment of technology since an autonomous way of powering the devices and the network equipment is required. The cost of the bandwidth is still expensive especially in Africa, though cellular or satellite coverage is available in those rural regions. The lack of local capacity in network administration and maintenance in these regions is another important inhibiting factor. Beside these constraints ([Johnson 2013]) reveals other ones like language and cultural barriers, transportation issues, tampering and theft (in some regions). Because network service providers are driven by profit, the low-density population with low-income in those regions cannot insure a return of investment. Moreover, in some countries, the lack of awareness about the potential of wireless networks to support the development of rural regions, leads the

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1 http://www.internetworldstats.com/stats.htm

government to do not define a clear policy to solve this problem. In contrary, law and regulations constitute a real barrier for providing some solutions like licensed spectrum policies.

3. Motivation

However, despite the impediments observed in rural regions, there are several reasons to consider these regions, especially in Africa. The first reason is that those regions host the majority of the population. According to ([UN DESA 2012]), in the second semester of 2012, the percentage of African population living in those regions is estimated to 60.1 percent. This represents a great market; and to take advantage, new business models should be developed.

The second reason is the rural exodus. The emerging policy of some African developing countries essentially relies on the agriculture that is mostly done in rural region. Therefore, rural exodus could seriously hinder their development. A report from U.N. Habitat ([Davies 2010]) states that 14 million people in Sub-Saharan Africa migrate from rural to urban regions every year. Considering this migration, the report predicts that more Africans will live in urban than in rural regions by 2030. This constitutes a real danger for the economy of these countries since it heavily relies on agriculture.

Although basic human needs are not completely satisfied in those regions, reaching information can provide access to education, to health information, help preventing disaster and so on. Some examples show how simple access to information can transform impoverished regions: Fishing industry in India, sunflower farming in Zambia. Even some social problems such as gender inequality can be overcame [Pejovic 2012].

4. The case of Cameroon

Cameroon is considered as Africa in miniature. Indeed, the climate diversity, the different cultures and reliefs of its rural regions expose different characteristics. In Cameroon we count 330 townships with 305 rural ones (more than 92%). But the rural population represents only 41.60% in 2010[2], compared to 47.46% in 2002. This diminution of the rural population is mainly caused by the rural exodus, as it is the case in Africa in general. This situation is a hindrance to Cameroon which intends to become an emerging country at the horizon of 2035; because its emerging policy relies largely on agriculture that is mainly done in these rural regions. Beside this objective to become an emerging country, one of the greatest projects from the Ministry of Telecommunication in Cameroon is the creation of Multipurpose Community Telecentres (MCTs). These are access points designed to provide ICT services, as well as postal and financial services to a community, at low prices. They are designed to be deployed in rural and suburban regions to fight against the digital divide between these regions that are generally neglected by private network service providers and urban regions that are more attractive in terms of return on investment. By now, 112 MCTs are already in operation and 90

2 http://www.tradingeconomics.com/cameroon/rural-population-percent-of-total-population-wb-data.html

are in launching phase. In the Adamawa region in Cameroon, we count 13 MCTs among which 06 are operational and 03 are functional. Table 1 provides some information about the localities where three MCT are deployed in the Adamawa region.

Locality	**MCT Powering**	**Population**	**Area (Km^2)**	**Density (h/Km^2)**	**Main Activities**
Mbe	Generator	12 000	3 000	4	Agriculture
Ngaoui	Panel Solar	15 000	2 307	6,50	Trade, farming
Tibati	Grid	46 563	8 000	5,82	Fishing and farming

Table 1: Selected Telecentres

5. Research problem statement

One of the perspectives of these MCTs is to cover a radius of about 35 km. To be achieved, it requires a careful design and deployment. While some work consisted in providing, from a nearby town, Internet access to a rural region using Wifi Long Distance (WiLD) or to improve an already existing community wireless network, one rather focuses on these questions: 1) How can this signal be spread at very low cost in a rural community that already has an Internet access (for example coming from one MCT)? 2) How can this network be useful and sustainable for the local community?

The research problem is the following: *Given a region to be provided with network connectivity from a telecentre (landline node), determine the minimum cost network architecture for ensuring minimal QoS and sustainability.*

The present study is conducted on real telecentres in Cameroon. Within the context of a rural region, this study will be concerned with the following research question:

1. How can the socio-cultural and geo-economic aspect influence design and deployment of network solution in a rural region?

2. Which technology is more suitable for Sub-Saharan rural region?

3. How can energy, throughput and scalability influence routing protocols performance in such a network?

4. How to optimally place the mesh router node of the network in order to maximize throughput and coverage while minimising the cost?
5. How can we estimate the overall cost of a rural wireless mesh network?

Question 1 is not a technological one; but it has to be carefully considered because this project needs an interdisciplinary approach [Pejovic 2012]. The socio-cultural aspect plays an important role as the success and the sustainability of the project depends on the users of the network.

Question 2 deals with the selection of the best technology according to the constraints of the environment.

For question 3, Routing metrics and protocols are determinant for the performance of the network. There exists a list of routing metrics and protocols for ad-hoc and wireless mesh networks, but they have to be evaluated considering the constraints.

When considering the fourth question, trying to maximize throughput and coverage seems to be a contradiction, since the coverage increases at the expense of the throughput. Therefore, a trade-off should be found while satisfying the minimum QoS and the minimizing the overall cost. In addition, mesh node placement algorithms usually assumes uniform propagation and same mesh node cost. But in this approach, we assume mesh nodes to have different costs (for indoor node and for outdoor node).

For the last question, providing a framework of cost estimation is very important for decision makers since they can appreciate more accurately the cost for an investment. Even for the project manager, to help him to avoid cost overrun during the deployment phase of the network. But this task is really bold, since the price is prone to change and architecture and configuration of mesh networks are not standard.

These questions are strongly related. Beside them, other questions should be considered like the security issue (personal data protection) and sustainability of the network. Since the environment is prone to change, to ensure the sustainability of the network, some possible changes must be considered as far as possible like the population growth, the increase of radio interference, the development of new business models and applications that may require more throughput otherwise the architecture would become early obsolete.

6. Assumptions

1. The present study is concerned only with the three localities where the selected telecentres are installed.
2. There is only one gateway in the network that is installed before planning the network (Especially the MCT Access Point) ; this gateway already has an Internet connection;
3. Radio interferences are low and only topology and energy constraints are considered during network planning.

7. Aim of the project

The aim of the project is therefore to design an economical and sustainable rural community Wireless Mesh Network and to provide a framework for the cost estimation.

8. Objectives

- To identify challenges and opportunities for deploying wireless mesh networks in rural regions especially in Cameroon;
- To identify relevant applications for these regions to sustain activities and communication;

- To provide a framework for selecting wireless network technology for rural region;
- To evaluate routing protocols according to energy, throughput and scalability;
- To design a flexible and scalable network architecture for these regions (indoor-outdoor nodes);
- To provide a framework for cost estimation of rural wireless mesh networks.

9. Wireless Mesh Networks

Trying to connect rural or remote regions, isolated locations or rugged terrain is not a new issue. Many experiences have already been made particularly in USA, in Europe and in Asia (mainly India) and even in Africa. In all these experiences, wireless infrastructures seem to be an appealing solution for these regions, since they are less expensive to deploy, mainly in hostile regions than the wired technologies such as ADSL or Cable.

Due to the lack of infrastructure in these regions, Wireless Mesh Networks (WMN) emerges as a solution to realize the dream to connect rural regions to the rest of the world. Indeed, Wireless mesh networks can easily, effectively and wirelessly connect entire cities or villages both locally and to Internet, using inexpensive existing technology. Unlike traditional networks that rely on wired access points or hot-spots to connect users, wireless mesh networks rely on wireless mesh nodes that communicate with each other, in order to share the network connection within a certain region. WMNs are dynamically self-organised and self-configured, with nodes in the network automatically establishing an ad hoc network and maintaining the mesh connectivity [Ian 2005]. WMN architectures can be classified into three main groups: Infrastructure/Backbone WMNs, Client WMNs, and Hybrid WMNs. Usually, two types of nodes can be distinguished: mesh routers and mesh clients. In addition to the routing capability for gateway/bridge of wireless routers, mesh routers also contain routing functions to support mesh networking. They have minimal mobility and form the backbone of the network. Mesh clients are more mobile than the router ones and can also work as router for mesh networking especially within a client WMN. But their software and platform can be designed much simpler than those for mesh routers.

Research is going on wireless network since more than two decades; and efforts have been particularly carried out for military service and urban regions in developed countries. But recently, there has been a renewed emphasis on developing wireless networks for rural regions. Most of the work was carried out in some parts of Asia, particularly in India; it tried to overcome the long distances between rural population and towns; distances that prevent them from accessing educational, medical, governmental or other services. The focus was on careful design of long link wireless networks usually called WiLD for Wifi Long Distance ([Sen 2007], [Flickenger 2008], [Surana 2009]). A typical deployment consists in linking a nearby city to a so called kiosk located in a remote village. Usually, these kiosks or points of interest host some basic services like Internet access [Seth 2006], health, call services or others. Although this prior kiosk model based results were satisfactory, the increase of user connectivity demand and the possibility to develop new business models, in order to bridge the digital divide, require more than just a kiosk model. Therefore, the aim is to spread this signal in a rural region rather than just provide the connectivity to a point of interest. Some works has been already done towards the deployment rural network [Chebrolu 2007], [Ishmael 2008], [Backens 2010].

9.1 Network planning and deployment

The first step in building a wireless mesh network is the network planning. But this step received little attention over the last few years; despite the plethora of studies that has been carried out on WMNs. Earlier WMN deployments did not use systematic approach in the planning. Consequently, these deployments have experienced a number of shortcomings tied to the connectivity problems (dead spots, lack of coverage) and performance problems (high latency and low throughput). Moreover, the scalability of the network could not be guaranteed and the overall cost of the system, which is the main concern especially in rural regions, did not received attention and therefore could not be estimated. Benyamina et al. [Benyamina 2012] examine and classify various methods that have been proposed either to improve the performance of an already deployed network or to improve the performance of a future network by a careful planning of its deployment. According to their classification, most of the work in network planning done in rural regions could be considered as partial design since they depend on exiting gateway(s). Sen et al. [Sen 2007] provide the first relevant work on this field in rural regions by formulating the problem in terms of variables, constraints and the optimization criterion. They propose a planning solution to provide a set of villages with long distance link from a given landline node (a Gateway). The optimisation problem is to minimise the overall cost of the network affected by the multi-hop network topology and the antenna tower heights under three constraints: throughput, interference, and power. The problem is broken down into four sub-problems: topology search (TS), optimum height assignment (HA), antenna assignment (AA), and power assignment (PA). To solve each sub-problem, they provide a formulation and use a different solution technique: Branch and Bound for TS, Linear Programming for PA and HA, and Heuristic algorithm for AA.

Similarly, Dutta et al. [Dutta 2007] provide another geometric formulation of the topology construction problem: given the location of the nodes, direct links between which nodes should be established such that, (1) all nodes are connected with certain robustness in the network, and (2) the cost of constructing towers to establish all the selected links is minimised. But they do not provide any algorithm to solve it.

Panigrahi et al. [Panigrahi 2008] provide amelioration of both [Sen 2007] and [Dutta 2007]. For [Sen 2007], they provide an algorithm with the worst-case logarithmic bound for prior heuristic. They provide an approach that can handle any number of obstructions between two nodes, while the prior heuristic considers only one obstruction. Finally, they provide algorithms that can handle a much more general cost function compared to the piece-wise linear cost function for the antenna towers associated to the prior heuristic. For [Dutta 2007], Panigrahi et al. provide the first algorithms for solving the topology construction problem with provable guarantees on the approximation factor.

In these works, the main concern is to connect a set of village from a landline node, using a long-distance links while minimising the cost by optimising the height of antenna towers. But the aim of our work is rather to spread the signal in a village from a landline node, by avoiding towers.

FRACTEL [Chebrolu 2007] partially tackles this problem by considering both long-distance network (LDN) and local access networks (LACNs). In this work, Chebrolu and Raman provide novels approaches to TDMA scheduling and channel allocation, but they do not provide a real approach for LACN planning. Although they argue that LDN and LACN at each village are independent of one another the key performance settings can be tuned independently.

Considering only local access network, Naidoo and Sewsunker [Naidoo 2007] evaluate the applicability of star mesh network [Zhang 2004] solutions to cover a rural region of South Africa, using the IEEE 802.11g standard. The main concern is to maximise the coverage, given a user node throughput (100 Kbps). But they also do not provide a concrete local planning approach.

[Backens 2010] proposes and analyses the performance of an indoor to indoor community based rural WMN using IEEE 802.11 equipment. Since in rural regions we usually observe a low density population constituted in sparse group of houses, to connect a community from a landline node, using indoor to indoor deployment, seems too difficult. Because indoor to indoor deployment could result in separated sub network, due to often long distances between groups of house.

Another work is [Wang 2007] where the authors study efficient mesh router placement in WMN. Their mesh router placement problem is the determination of a minimum set of positions among the candidate positions in such a way that the mesh routers situated in these positions cover the given region, maintain the full connectivity toward the internet gateway and meet the traffic demand.

To obtain an efficient and sustainable network, the planning process should take into consideration more than just the technical aspect. Szabo et al [Szabó 2007] suggest a design methodology going from the identification of applications and services to the cost calculation of the final network. But this design methodology is more adapted to city than to rural regions, since it does not consider, in a particular manner, sparsely populated regions with low income revenue. Mendez-Range and Lozano-Garzon [Mendez-Range 2012] provide a design methodology for rural areas of developing countries, but this one is specifically designed for e-health services. To support local development, a rural multi-purpose network should be planned. It should support local activities, education, health services while considering the constraints of the region.

9.2 Our approach for deployment

For reasons of cost minimisation, we firstly differ from previous works by defining a mixed approach (indoor-outdoor). We distinguish two types: indoor and outdoor. To each type, we assign a cost factor. In the respect of coverage and throughput, wherever possible, an indoor node is preferred to an outdoor one.

What we call indoor node is not a real one. It is rather an outdoor node installed on a rooftop of a house or other building and which uses a grid power. In contrary to real outdoor node that will need a mast and independent source of powering (like solar panel).

The cost functions defined in prior works are no longer adapted, since it is based on tower heights, towers are avoided in this planning process. Therefore, there is a need to redefine the cost function.

Although avoiding antenna towers reduces significantly the cost of the network deployment, the outdoor deployment is still costly, because it requires usage of mast, independent source of powering (for example solar panel) that can be avoided by using grid power and rooftop in indoor deployment. Moreover, the security aspect provided by indoor deployment is not trivial.

Unlike urban regions, where the population density is high, in rural regions we usually observe a low density population, constituted in sparse group of houses which are separated with large spaces that can be empty or used for farming, fishing, or agricultural activities. Finally, with the aim of minimizing the overall network deployment cost, there is no need to plan to cover a whole region. For a given region, areas of interest could be defined. However, the network architecture must be scalable to allow some future extensions in term of coverage.

10. Methodology

Planning a WMN especially in rural region is not only a technological matter, because its success and sustainability depends on its integration in the daily life of the end users. This integration can be achieved only if the planned network finds a trade-off between what users need and what they could afford. To find a good trade-off requires a suitable approach. Our design process model is illustrated in Figure 1.

Step 1: **Analysing Regions**

Here, we deal with the first research question. This question is not only geographical; we have to also deal with socio-economic aspect. First, we select three zones based on the localisation and ethnic group (culture). As ([Johnson 2013]) reveal, social aspect (especially cultural) and natural environment influence the success of the implementation of a wireless network in rural regions.

After selecting the different areas, we will do a survey based on the following criteria:

- Geo-economic considerations: Density of population, main activities, population incomes and growth rate (for sustainability), topology and surface, climate. Population growth can easily bring more changes in the environment and also in term of network requirement.
- Infrastructural considerations: roads, energy supply, building, markets, internet access points;
- Technological considerations: computer, mobile device (cell phone, tablet PC…), Network operator, Radio and TV spectrum availability (White spectrum availability);
- Governmental considerations: spectrum regulation, other laws and regulations, government interest (services and future projects);
- Cultural considerations: cultural barriers to technology penetration;
- Skill considerations: local competence, ease of troubleshooting, people motivation.

For the survey, we will use questionnaires and conduct Free Attitude Interviews (FAI). This may require an interpreter. Data will be collected and synthesized in order to provide relevant information for the rest of the design process.

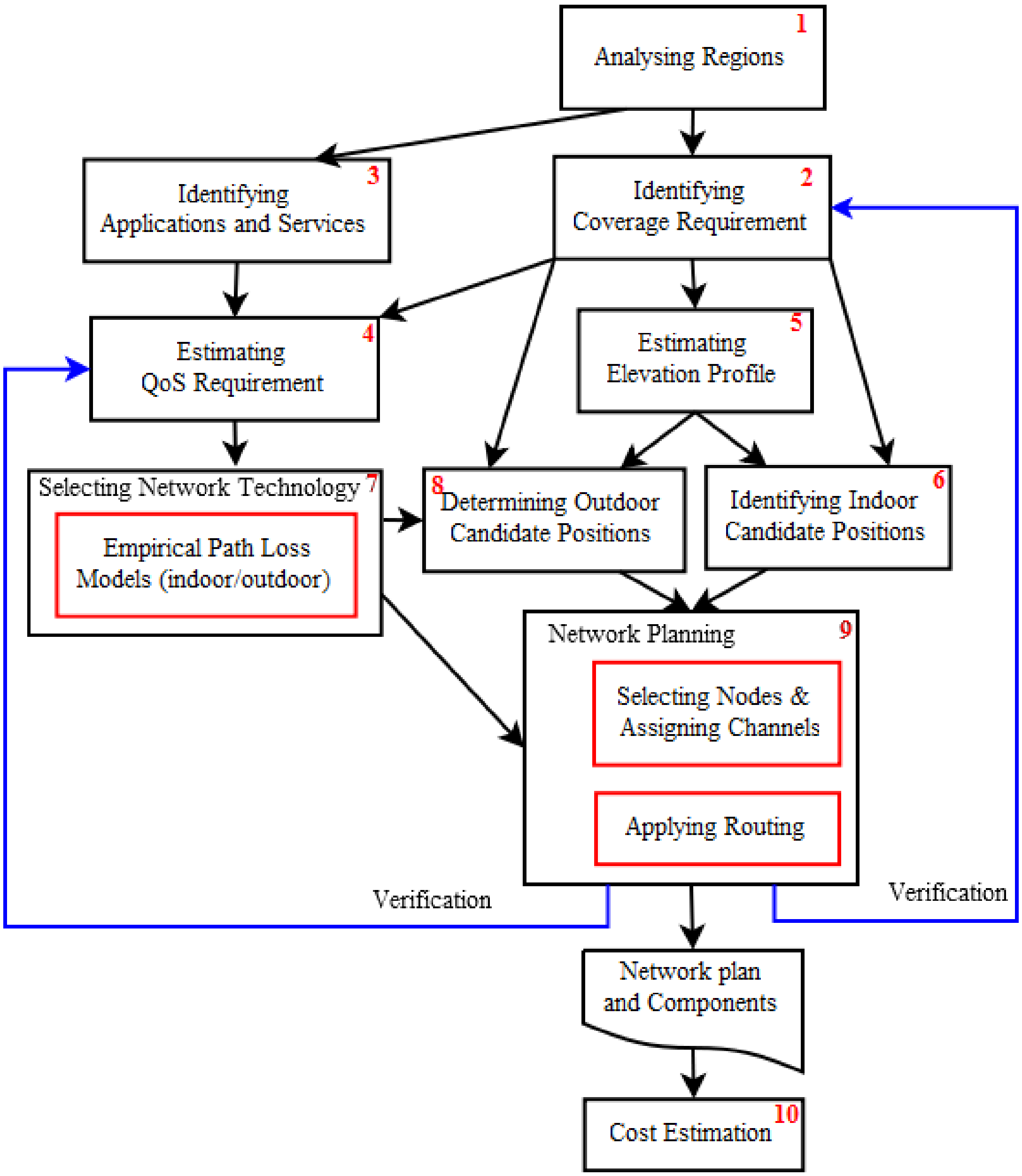

Figure 1: Design process model

Step 2: Identifying Coverage Requirements

At this step, we circumscribe Areas of Interest (AI), where the signal must be spread from a telecentre. By applying Divide And Conquer method, each area of interest is divided into Elementary Area of Interest (EAI) for better handling, from the gateway location to the edge of the AI. Let E be the set of EAI. For each ei in E we estimate the number of potential simultaneous users of ei. For sustainability reasons, on a ten years period, we define two factors affecting ei: geographical dispersion factor di and population growth factor gi.

Step 3: Identifying Applications and Services

Here we will identify relevant applications and services the network should provide and their requirements (especially the throughput). We will try to estimate the need of one user in term of throughput. An extension of this step is to provide a framework for the design and deployment process of these applications and services on the network. For example, since the bandwidth is usually low in these regions, using caches to avoid huge amount of data traffic on network is an interesting option.

Step 4: Estimating QoS requirement

A trivial way to estimate the QoS requirement, considered here as the throughput only, is to multiply the application and service requirement for one user by the number of simultaneous users. A more realistic approach is to estimate the budget of every link of the network and to determine the budget at the Gateway. The geographical dispersion and population growth factors should be considered for sustainability reasons.

Step 5: Estimating Elevation Profile

The elevation profile provides the height of nodes. Because there is no great change in term of price, we will assume that all outdoor nodes have the same mast height. We want to check here that 10 meters is enough for a mast. A more realistic approach is to determine for each EAI ei the associated profile elevation. Google Earth is a useful tool.

Step 6: Identifying Indoor Candidate Positions (ICP)

ICP are chosen among houses or buildings which provide grid energy. Relevant characteristics of an ICP are the elevation profile, which can help avoiding high mast, and the energy quality. ICP reduce the cost of deploying an indoor node, when comparing to an outdoor node.

Step 7: Selecting Network Technology (Empirical Path Loss Models)

The more appropriated technology is IEEE 802.11(WiFi) because of his lower price when compared to IEEE 802.16 (WiMAX) which in turn provides a greater coverage. IEEE 802.11 standard has many extensions; however we will focus on only two: IEEE 802.11g and IEEE 802.11n. We study the empirical path loss models in order to answer to the following question: at which maximal distance d can we obtain the minimal throughput t? This is done by taking measurements on terrain and comparing these results to selected prediction models. The best model is therefore optimised in order to obtain a more précised prediction model. For on-terrain measurements, vistumbler for received signal strength, ttcp and iperf for throughput and usb gps for distance are used.

Step 8: Determining Outdoor Candidate Positions (OCP)

OCP depend on the results of the empirical path loss models of step 7, because they are determined using these results and coverage requirements from step 2. From the gateway, we determine all the possible OCP by mapping the region to cover with a pattern representing an OCP coverage according to the transmission range of the selected technology.

Step 9: Planning Network

It is the most important step in the design process. It is composed of two main phases: Selecting nodes and Assigning Channel, and Applying routing protocol.

- **Selecting nodes and Assigning Channels**: After determining the set of possible links, filter the set to obtain the minimum set which satisfies the total coverage of the region. We define a multi objective optimization approach in which we minimise the number of outdoor nodes, minimise the total number of nodes, when maximising the throughput in the respect of coverage requirement. To benefit from the multi-channel of nodes we can study how to apply the graph colouring approach [Dutta 2008] when using non-interfering channels (for example 1, 6, and 11). Mix-Rx-Tx interference that is due to simultaneous transmissions and receptions on the same node can be avoided.
- **Applying Routing**: Energy, scalability and throughput are of interest. We will evaluate three routing protocols: Ad hoc On demand Distance Vector (AODV), Optimized Link State Routing (OLSR) and Hybrid Wireless Mesh protocol (HWMP) according to these three constraints after selecting the suitable routing metrics and an energy consumption model. Eventually, we will try to optimize the best routing protocols. We use NS3 for simulation.

At the end of this step, verifications should be made in order to check if the QoS and coverage requirements are met. If it is not the case, distances are reduced to improve the throughput. Outdoor nodes are re-determined and step 9 is performed again. This loop is performed until the requirements are met. Therefore, the list of components is produced.

Step 10: Cost Estimation

With limited budget in rural regions, it is important to accurately estimate the deployment cost of the network in order to avoid cost overruns. After the planning, the list of component with dominant cost will be generated. Based on it and using distribution probabilities, a framework for the cost estimation will be built.

11. Expected Outcomes

- A design methodology for rural wireless mesh network; (paper accepted for the 6th

AFRICOMM conference);

- Framework for network technology selection in rural environment;
- Performance evaluation of routing protocols for rural wireless mesh network;
- Algorithms for Mesh Nodes placement in rural region;
- Cost estimation framework for rural wireless mesh network.

12. Work Schedule

Task	Start	End	Days completed	Days Remaining
Preliminary study	28/02/2012	27/05/2012	89	0
Literature Review	30/05/2012	28/02/2015	493	511
Research Method	10/02/2013	25/05/2013	104	0
Proposal Writing	20/04/2013	25/08/2013	127	0
Regions Analysis	16/09/2013	20/12/2013	19	95
Network technology selection	27/09/2013	22/01/2014	8	109
Routing protocols evaluation	07/01/2014	18/07/2014	0	192
Mesh Node placement	15/06/2014	06/01/2015	0	205
Cost Estimation	22/11/2014	25/03/2015	0	123
Thesis write-up	01/03/2015	12/06/2015	0	103

Table 2: Work Schedule

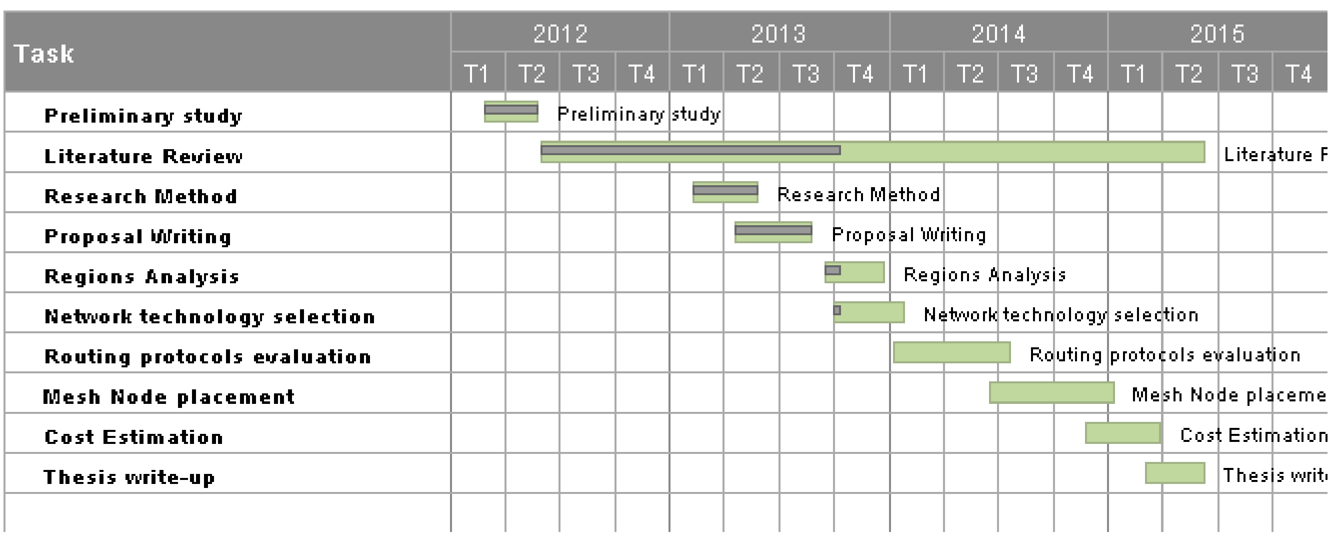

Figure 2 : Gantt Chart

13. Thesis structure

The proposed structure of the thesis is the following:

Chapter 1 is an introduction presenting the content, target and also the motivation of this study.

Chapter 2 provides background on rural wireless network planning and deployment.

Chapter 3 presents a case study of three selected regions in Cameroon.

Chapter 4 discusses on rural network technology selection and empirical path lost model.

Chapter 5 provides different approaches for efficient mesh nodes selection and placement.

Chapter 6 presents and evaluates routing protocols for the mesh network.

Chapter 7 provides a framework for network cost estimation.

The last part of the document presents open problems and the general conclusion.

14. Selected Literature

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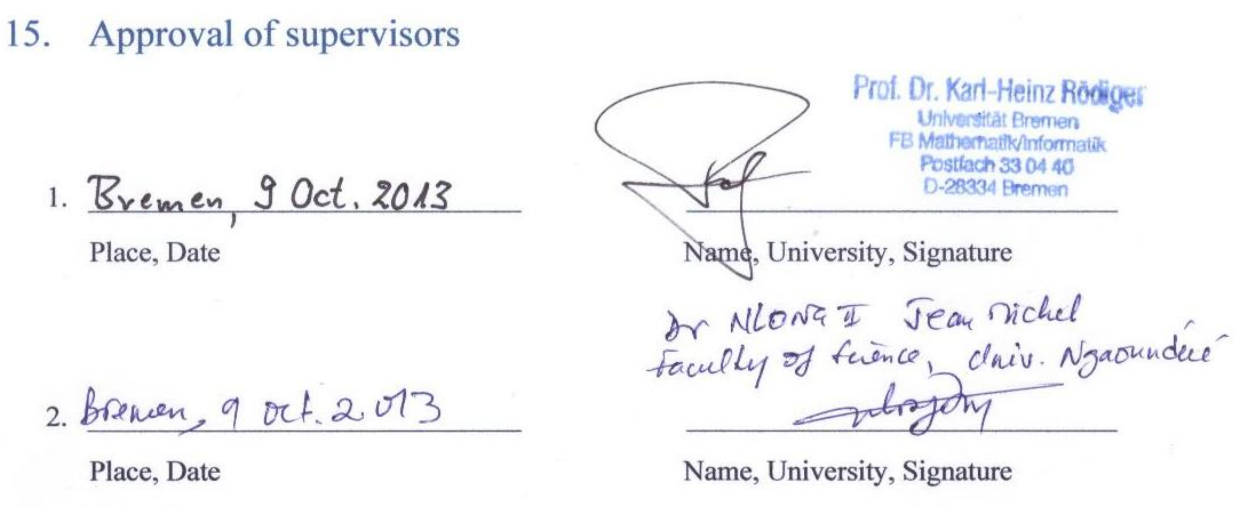
15. Approval of supervisors


15. Approval of supervisors

1. Bremen, 9 Oct. 2013

Place, Date

Prof. Dr. Karl-Heinz Rödiger
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FB Mathematik/Informatik
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Name, University, Signature

2. Bremen, 9 oct. 2013

Place, Date

Dr NLONG II Jean Michel
Faculty of Science, Univ. Ngaoundéré

Name, University, Signature