Converged Infrastructure for Emerging Regions - A Research Agenda

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Abstract. In remote parts of Africa, the lack of energy supply, of wired infrastructure, of trained personnel and the limitation in OPEX and CAPEX impose stringent requirements on the network building blocks that support the communication infrastructure. Consequently, in this promising but untapped market, the research aims at designing and implementing energy-efficient, robust, reliable and affordable wide heterogeneous wireless mesh networks to connect geographically very large areas in a challenged environment. This paper proposes a solution that is aimed at enhancing the usability of Internet services in the harsh target environment and especially how the end-users experience the reliability of these services.

Keywords: AMC, beamforming antennas, cross-layer, network monitoring, cognitive self-configuration and self-management, converged infrastructure;

1 Motivation and Concept

The internet penetration in Africa is still extremely low (2-3%) and even less in rural areas. In year 2007, there were only two million fixed broadband subscribers in whole Africa where the population is about 1 billion. Especially, the penetration in Sub-Saharan region is very low due to the lack of required telecommunication infrastructure and low gross domestic product per capita. Nevertheless, the trend in the growth of Internet services is very promising especially when looking at the growth rate of other ICT services.

When compared with the internet usage, mobile telephony has found a substantial acceptance in those regions (See Figure 1). There are currently more than 250M subscribers in all over Africa, and this number has increased exponentially over the years.

One of the most influential reasons behind this discrepancy between the penetration of mobile services and internet services lies in the fact that internet costs are extremely high in Africa due to the lack of terrestrial networks and high usage of satellite based Internet services.

Even if a price reduction about 25% is considered from year 2006 to 2007, it is clear that mobile telephony costs nearly one fourth of internet services. Additionally, the Internet services in Africa were in year 2006 over twice more expensive than in Europe. When the gross domestic product (GDP) per capita is taken into account [1],

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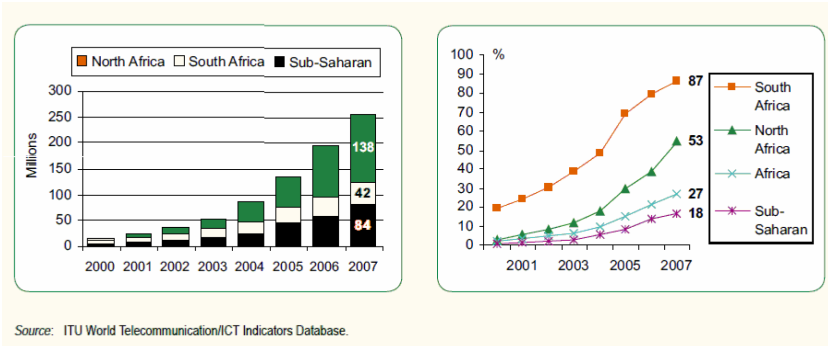

Fig. 1. Mobile Services in Africa 2001 – 2007 [ITU]

the Internet service costs are twenty to thirty times more expensive in Africa than in Europe. Therefore, it is clear that Internet services are currently beyond the reach of most people in Africa.

One of the key reasons is the lack of reliable infrastructure especially in rural areas. This paper proposes a solution that is aimed at enhancing the usability of Internet services in the harsh target environment and especially how the end-users experience the reliability of these services. The main objective is to design and implement energy-efficient, robust, reliable and affordable wide are heterogeneous wireless mesh networks to connect geographically very large areas in a resource challenged environment.

2 Vision and Challenges

What is the future in terms of communication infrastructure in rural Africa? There are over 400 000 localities on the continent, of which 99 percent are villages, up to two-thirds of the people live in rural areas. In these areas, less than four percent have a fixed line telephone connection and while mobile communications have made huge inroads in providing connectivity to villages, about half of African villages were not covered by a mobile signal in 2006. In few cases where Internet access is available, it is provided via expensive satellite connection. There are isolated cases where satellite Internet access is extended to surrounding villages via the deployment of infrastructure-less networks such as mesh networks (mesh islands). Examples of such exist in South Africa and in Zambia [7].

In our vision, the mesh islands will be interconnected and these interconnected heterogeneous (WiFi, Wimax, satellite, cellular networks) mesh networks will provide the (wireless) terrestrial connectivity covering very large areas as depicted in Figure 2. Consequently, communication infrastructure in emerging regions (Africa and parts of Europe) will be based on heterogeneous wireless mesh networks to connect geographically very large areas in an extremely harsh environment.

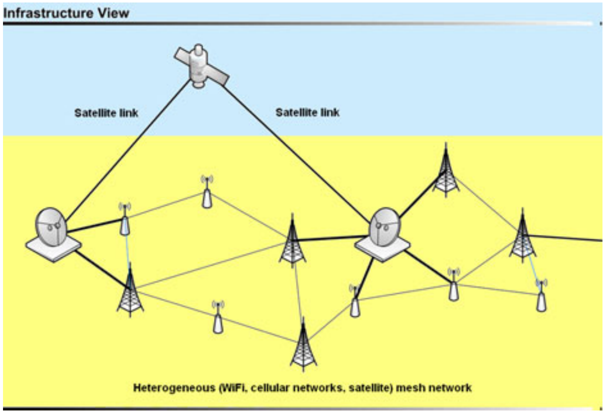

Fig. 2. Converged Infrastructure for Emerging Regions

Imposed by the characteristics of the harsh environment, the following key challenges of the envisaged wireless mesh network should be solved:

1. **Lack of reliable energy supply;** R&D challenges include:
   a. energy-efficient equipment and communication technologies (including communication protocols)
   b. energy supply based on solar power and radio/network/management technologies/approaches to handle limitations and variations in power supply
2. **Lack of wired infrastructures;** Hence, the wireless mesh will be very large in terms of distance and in terms of hops. This requires routing protocols that can handle and adapt to the specifics of multi-hop wireless, particularly considering a lot of lousy hops, unreliable nodes and limited bandwidth. R&D challenges include:
   a. development of radio infrastructures for large area wireless multi-hop multi-technology connectivity
   b. development of routing protocols that support such a mesh-topology infrastructure efficiently
3. **Lack of well-trained service-personnel;** leading to the requirements of self-configuration, self-management and self-healing equipments and protocols. R&D challenges include:
   a. development and deployment of self-managed and self-healing equipment
   b. development of adaptive radio technologies for these environments
   c. determination of network dynamics and development of respective network management and service provisioning mechanisms
4. **Limitations to OPEX and CAPEX due to limited financial capabilities of target customers** (in order to ensure a business case for sustainable network deployment); Equipment needs to be low-cost enabling local operators to provide affordable services to some or all potential users. In Africa, the monthly mobile prepaid average tariff basket was US$ 12 in 2007.

3 Example

In order to highlight the confronted environment that imposes the same requirements on the infrastructure that needs to be developed, a view of a typical rural African settlement is shown in the picture below. As can be seen from the type of vegetation, multi-path effects and scattering are relatively low. Also, the relative position between houses shows that, typically, there are at least one or a couple of low buildings in the immediate vicinity of each other. The distances between sets of buildings are in the order of few hundred meters to a few kilometres. The height of the buildings on the one hand simplifies propagation but on the other hand does not provide any sufficiently tall infrastructure for efficient broadcasting. The solutions for a typical city environment may not be appropriate for the environment depicted here.

Fig. 3. Typical landscapes of rural South Africa

One of the challenges in rural Africa is the lack of reliable power supply. Typical solutions for these are to power devices with batteries that are sometimes recharged by solar energy. Under these conditions, some of the communicating nodes are bound to run out of power and fail, i.e. become unavailable for routing any messages. In a traditional network with fixed hierarchy, this scenario would mean unavailability of communication for all the nodes which rely on the failed node for relaying their messages. The mesh network topology provides greater flexibility and permits self-healing of the communication infrastructures, taking advantage of alternative routing. Under this scenario, the low-cost solutions such as the one depicted in Figure 4 will not work as it requires manual intervention to change its direction. Appropriate solutions need to have the ability to change direction automatically. Smart antenna systems have the ability to change the direction of the beam on demand permitting a quick switch-over to an alternative route. Another challenge is scarcity and often absence of skilled personnel. The ability of a system to perform as much of the setting up, re-configuration, balancing etc. seamlessly and automatically is critical for making communications available and sustainable in the short to medium term.

Fig. 4. Installation of a DIY kit for wireless communications, provided by the Meraka Institute of CSIR

Figure 4 shows installation of a do-it-yourself WiFi based communication kit deployed by the Meraka Institute of CSIR in the recent past. The antenna used is made of a metallic coffee can. This antenna, just as most of traditionally used antennas are fixed to the wall, does not have any degree of control. Thus, the link cannot be changed without manual intervention.

4 Relevant Work

Project	Missing elements
CARMEN	Carrier-grade mesh networks (CARMEN) looks at mesh networks through the view of a telco operator [2]. In particular, it is assumed that the network is very well planned, energy is not an issue and neither are costs. Well-trained engineers are always at hand relieving several of the typical constraints in wireless mesh networks. In Africa, we do not have the comfortable fully controlled environment of CARMEN, neither the requirements to provide 24/7 carrier-grade service.
WIDENS	A validation of Mobile Ad-hoc Network (MANET) deployment for emergency case was done in FP6 project WIreless DEployable Network System (WIDENS) [3]. To cope with the situation in Africa, a complement of WIDENS' scope is needed by considering other radio broadband links and also by demonstrating how ad-hoc networking helps to offer interaction with other wireless connections such as satellite and existing narrowband system.
Self-NET	Self- management of cognitive future internet elements (Self-NET) focuses on self-management of network nodes and subnets based on a cognitive feedback-control cycle. While Self-NET assumes a rather stable infrastructure, where network dynamics typically arise from changing traffic patterns, due to the situation in Africa environmental impacts on

Project	Missing elements
	network capability, stability and performance need to be considered. In addition, Self-NET (like most other projects) assumes an abundance of energy and transmission capacity to be available for internal network management. Additionally, there is no mesh relevant scope of Self-NET.
SOCRATES	Self-Optimisation and self-ConfiguRATion in wirelEss networks (SOCRATES) [4] project aims at the development of self-organisation methods to enhance the operations of wireless access networks by integrating network planning, configuration and optimisation into a single, mostly automated process requiring minimal manual intervention. While SOCRATES focuses mainly on cellular networks, concepts developed in this project could be reused for a converged infrastructure in emerging regions.
N4C	Networking for Communications Challenged Communities (N4C) [5] project is looking at ways to extend Internet access to remote regions that do not have reliable and affordable network access today. N4C focuses particularly on Delay Tolerant Networks while for a base providing an always-available infrastructure is needed.
FMFI	First Mile First Inch (FMFI) [6] is a project that was conceptualised by the Wireless Africa team at Meraka Institute of the CSIR with the aim to identify and develop models and technology in order to overcome the problem of access to communication and information services in low-density (rural) areas. In FMFI, no architecture for converged infrastructure is provided.

5 Objectives and Outcome

Based on the challenges mentioned in the previous section, the clear objective is to design and implement energy-efficient, robust, reliable and affordable wide area heterogeneous wireless mesh networks to connect geographically very large areas in a challenged environment. This general objective is translated into a number of more specific objectives organized along the following themes:

- The development of novel Adaptive Modulation and Coding (AMC) and smart beamforming antennas to adapt radio transmission to the availability of energy
- The development of a network monitoring based on self-configuration/self-management techniques deployed in a large multi-radio meshed converged infrastructure to cope with the lack of human resources and wired infrastructure
- The design of a cross-layer architecture to support message forwarding mechanisms in order to optimize power consumption and content delivery

After being equipped with the proposed ICT solutions, the envisioned system will have a key role in enhancing the usability of internet services in the harsh target environment and especially how the end-users experience the reliability of these services. The objectives are further detailed out in the remainder of this section.

5.1 To Develop a Novel Adaptive Modulation and Coding Scheme to Optimize Energy Consumption

The concept of adaptive modulation and coding (AMC) is to change the Modulation and Coding Schemes (MCS) dynamically with the changing channel condition to increase the overall spectral efficiency. The AMC schemes will be used to adapt radio transmission to environmental changes (weather conditions), transmission requirements (amount of data) and availability of energy.

5.2 To Develop Smart Beamforming Antennas to Optimize Energy Consumption

Smart beamforming antennas will be used to develop an inexpensive energy- and spectrum- efficient smart antenna system for replacing the commonly used omnidirectional antennas. This antenna system will be able to focus the radiated/received electromagnetic energy in a specified direction. This lowers energy consumption, improves spectrum re-use, channel capacity and/or increases the communication range.

In order to access all available neighbouring nodes, this antenna requires steering the beam over the 360 degrees in the horizontal plane. An *intelligence engine* will provide the ability to identify the sources of interference, to form radiation patterns shaped to be insensitive in the direction of interference found and to tune the transmitter's output power to a minimum necessary level. A cross-layer mechanism will permit switching between routes/directions according to the commands from the medium access control (MAC) or networking layers.

The ability to command the shape of antenna's radiation pattern and position the beam in the desired direction, as well as information derived from the link and channel measurements, will be used to simplify set-up and maintenance of the network, contributing to self-configuration and self-management.

5.3 To Design a Cross-Layer Architecture to Support Message Forwarding Mechanisms in Order to Optimize Power Consumption and Content Delivery

Such a cross layering approach will require an interface among different network layers enabling the exchange of the information and respective software modules that are able to receive and interpret this information. IEEE 802.21 is a nice example for a cross layer protocol enabling the cooperation between MAC layer and the upper layers. With an approach similar to IEEE 802.21, we will define primitives between neighbouring layers enabling both central and distributed information exchange including energy specific information, end-user characteristics and network properties such as the vulnerability of TCP connections to SATCOM links, which is widely the case in rural areas.

5.4 To Develop a Network Monitoring System and Cognitive Self-configuration and Self-management Mechanisms to Cope with the Unreliability of the Environment of Emerging Regions

Intelligent network monitoring will be used to reduce the amount of information required for assessing performance and experienced QoS of coexisting wireless systems. The problem is that the most important indicators e.g. end-to-end delay or end-to-end jitter cannot be obtained reliably and collected data from networks contain a high degree of irrelevant data, which gets needlessly processed.

Another objective is to alleviate problems originated from lack of technical personnel, unreliable power supply and abnormal traffic load situations in a multi-system environment by enhancing self-configuration and self-management capabilities of network nodes. These capabilities are also essential to ensure sufficient quality of service for end-users and maximal utilisation of scarce radio resources. Providing intelligent and agile self-configuration and self-management support for coexisting networks is essential.

5.5 To Create a Converged Infrastructure to Improve the Use of Different Available Wireless Network Access Means

A converged infrastructure for emerging regions includes a mesh-network where several compositions of multiple transmission technologies will be available routing traffic from source to destination alternatively. An example might be a choice between interconnected WiFi-stations, longer-range Flash-OFDM and meshed satellite links (both composed and alternatively). For this purpose, the most appropriate technologies (e.g. IEEE 802, 3GPP, LTE, Flash-OFDM, DVB…) suitable for the envisioned regions of Africa and Europe and the expected demand for connectivity within those regions will be determined.

In order to provide generic support for service continuity across these networks, it is necessary to describe and propagate service requirements and to set and request link-layer functions and capabilities (also for alternative paths of concatenated links). Hence, a media independent interface for the management of the determined technologies will be prepared. Different than IEEE 802.21, this interface will have the main focus on building and managing *heterogeneous mesh networks*. Hence, the studies will concentrate either on a new protocol dedicated to media independent mesh technologies or on an amendment to the existing IEEE 802.21 extending its functionalities for mesh networks.

6 First Steps towards a Solution

LinkNet Zambia [7] has been developing a WiFi based mesh solution for rural Macha, which is located in the Southern Province of Zambia. Because of the lacking fibre connection to the core network, Internet is provided through two satellite gateways based on C-Band (128Kbps downlink / 256Kbps uplink) and Ku-Band (512/256Kbps). Due to high costs of satellite connection, the available bandwidth is distributed throughout other facilities in need of internet connection via a mesh network. For the efficient functioning of the mesh network, different components such as monitoring and load balancing modules are already implemented.

However, the very dynamic structure of the region requires that the available bandwidth is further propagated to nearby campuses, such as the Ubuntu Campus that is about 3km away from Macha centre. Considering the low available bandwidth, frequent power downs and the harsh climate of the area, this is a challenging task; but on the other hand a one-time opportunity for a proof of concept. Therefore, Fraunhofer FOKUS is now developing a WiFi based solution based on the concepts of this study. The solution should build the basis for a more developed architecture ensuring reliable and efficient network utilization both in Macha Centre and Ubuntu Campus in the long term.

Fig. 5. Connecting Ubuntu Campus and distribute Internet access wireless

Currently, for the long distance connection of Macha with Ubuntu Campus low cost WiFi devices are deployed. Within Ubuntu Campus the connection is supplied through a mesh network. The target is to further improve this testbed so as to enhance the functionalities of these devices by smart software and inexpensive additional hardware. In order to increase the available bandwidth and the stability of the network, advanced routing protocols and autonomic configuration of the physical layer are developed. Transmission power, modulation type and used frequencies can be adapted automatically if a physical layer with cognitive skills is used. In addition to different antenna types like omnidirectional, yagi and parabolic, also smart antennas adapting to the current situation, e.g., by changing directions in case of node failure, will be used.

7 Conclusions

To provide a communication architecture for emerging regions, there is a need for a holistic approach to tackle a number of challenges described in this paper (lack of reliable energy supply, lack of wired infrastructures, lack of well-trained service-personnel, limitations to OPEX and CAPEX due to limited financial capabilities of target customers). The robust and reliable resulting infrastructure will be supported by a wide range of technologies (heterogeneous WiFi, Wimax, satellite, cellular networks) providing vital services to the population. The envisioned social impact is tremendous in line with the potential market share gain. Finally, to enable this research roadmap to come true, a strong cooperation is needed between research institutes from emerging and developed regions supported by a favourable policy environment.

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