UNIVERSITY OF AGDER
FACULTY OF ENGINEERING AND SCIENCE

PhD project description

Routing and scheduling in a multi-hop wireless mesh network for emerging economies

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1. Information

PhD programme:	Mobile Communications Technology
Project title:	**Routing and scheduling in a multi-hop wireless mesh network for emerging economies**
PhD student:	Gerard Rushingabigwi
Principal supervisor:	Prof. Dr. Frank Reichert
Institution:	University of Agder
Co-supervisor:	Dr. Lei Jiao
Institution:	University of Agder
Co-supervisor:	Prof. Dr. Josef Noll
Institution:	University of Oslo/UNIK
Co-supervisor:	Associate Prof. Dr. Etienne Ntagwirumugara
Institution:	Kigali Institute of Science and Technology (KIST)
Start date of the PhD project:	September 2012
Expected date of completion:	June-July 2016

The following current regulations apply:

- Regulations for the Degree of Philosophiae Doctor (PhD) at the University of Agder
- Supplementary regulations for the PhD programmes in ICT and mechatronics / technology

Signatures

		Gerard Rushingabigwi
Date	Signature, PhD student	Printed name
		Frank Reichert
Date	Signature principal supervisor	Printed name
		Lei Jiao
Date	Signature co-supervisor 1	Printed name
		Josef Noll
Date	Signature co-supervisor 2, if any	Printed name, if any
		Etienne Ntagwirumugara
Date	Signature co-supervisor 3, if any	Printed name, if any

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Does the committee (REC/PPCM) recommend the PhD project description? YES ❑ NO ❑

Comment, if any:	
Date	Signature, REC/PPCM

Date and signature, for the faculty: Dean

2. Coursework component

Up to 10 credits may be taken as national or international research courses and/or special syllabus courses.

For ICT (30 credits where at least 20 credits technological and/or science subjects):

- Breadth courses (B): 15 credits, including at least 5 credits on research ethics and scientific theory as EX-602 *(to be marked with B in the coursework component table below)*
- Specialization courses (S): 15 credits *(to be marked with S in the coursework component table below)*

For mechatronics (30 credits where at least 20 credits technological and/or science subjects):

- MAS601 and MAS602 are compulsory and multi-disciplinary common core material (MAS602 is optional for PhD student that specializes in renewable energy)
- At least 5 credits on research ethics and scientific theory as EX-602
- Normally, three of the courses MAS701, MAS702, MAS703, and MAS704 are to be selected, such that the specialization courses, along with the dissertation, provides professional breadth and depth

Table 1: Coursework component table

Course code	Course name	B/S	Credits	Institution	Semester
UNIK9290	Mobility in the Internet	S	10	UiO/UniK	Spring 2013
IKT715	Advanced topics on selected areas in ICT: Internet for emerging economies	S	5	UiA	Autumn 2013
UNIK9700	Selected topics in radio and mobility	B	10	UiO/UniK	Autumn 2013
EX602	Philosophy of Science	B	5	UiA	Autumn 2013

'For ICT: B = breadth courses, S = specialization courses

Special syllabus courses have to be approved by the faculty. Alterations in the coursework component and special syllabus courses must be approved by the supervisor, and must be assessed by PhD programme committee (REC for ICT and PPCM for mechatronics). Special syllabus course description template and application form for changes may be found via www.uia.no/tekreal/phd/tek/documents.

3. Contact information for external supervisor(s)

Contact information for any supervisors that are not employed at UiA is included in table 2.

Table 2: External supervisor(s) details

Name	Position	Work place	Telephone	Email address
Josef Noll	Professor and Member of CWI Norway	University of Oslo/UNIK, Connected Life, N-2027 Kjeller	Ph: +4764844745, Mob:+4790838066	josef@unik.no
Etienne Ntagwirumugara	Associate Professor and Coordinator of Rwanda Education Network.	Kigali Institute of Science and Technology (KIST)	Mob: +250788353874	e.ntagwirumugara@kist.ac.rw; e.ntagwir@yahoo.fr

4. Dissertation and progress plan including dissemination of research results

The time schedule for the PhD project is outlined below *<NB: this is an example. The PhD student has to fill in relevant information. Gantt chart may also be included>*.

Year*	Month	**Research stages***** the dissertation plan should indicate the research stages in a way that the stages are verifiable, for example theoretical studies, detailed study, analysis, programming, computer simulations, lab-/field work, publications, writing the dissertation, trial lecture and disputation etc.
2012 (Done)	9-12	✓ Literature review and finalization of the PhD project description. ✓ Administrative arrangements for the first presentation in Norway by January 2013. ✓ Progress report to the supervisors.
2013	1-4	• Finalization of the PhD project description • Meetings and discussions with the supervisors; • Structuring the first publication paper; • Attendance to the spring 2013 course work; • The PhD forum presentation (in March); • Preparation of a publication paper; • Continuation of literature review.

	5-8	• Finalization of the spring semester's exam and assignments. • Exercises on some programming and simulations; • Finalizing the first publication paper. • Progress report and discussions with the supervisors.
	9-12	• Attendance to the autumn semester's courses; • The PhD Forum presentation (October)**;** • Designing the skeleton-system for the multi-hop wireless mesh network
2014	1-8	• Intensive work on the next two publication papers whose titles will be chosen in consensus with the supervisors.
	9-12	• Discussion with the supervisors in Norway; • The PhD forum presentation (October); • Designing and practicing the optimization algorithms for route scheduling to the wireless mesh networks in question. • Doing the course works examinations which will not have been accomplished; • Gathering data for writing the final PhD dissertation report. • Progress report to the supervisors.
2015	1-3	• Implementation of some algorithms for the routing and scheduling in WMNs.
	9-12	• Submitting the last publication papers prior to graduation; • Doing the 4th PhD forum presentations around University of Agder (October); • Doing **the trial lecture and disputation at the University of Agder.** • Final activities related to the final PhD dissertation report. • Progress report to the supervisors.
2016	1-3	• One publication paper;
	4-7	• Corrections on the PhD final dissertation report; • Defence of the final PhD dissertation and its related duties.

* *The dissertation plan should be in more detail the first year, compared to the second and third year*

** *The trial lecture and disputation are approximately 3-5 months after the end of PhD research fellowship*

**** The dissertation plan should contain self-evaluation criteria that can be used by the PhD students. This can for example be the SMART criteria. SMART[1] is an acronym for: Specific - clearly specifies what the research will consist of - the objectives, Measurable - criteria and plan suitable to monitor progress on when objective is achieved, Attainable - the research plan has a realistic ambition level, Relevant - the research plan is relevant, both with my own goals and desires and the needs of UiA, Timely - clear time frame for the objective including interim steps.*

The Gantt chart below (next page) illustrates the timeline for the planed PhD project description, including both the course framework and the research main activities.

	2012		**2013**		**2014**		**2015**		**2016**	
Research Main activities		Autu-mn	Spri-ng	Autu-mn	Spri-ng	Autu-mn	Spri-ng	Autu-mn	Spri-ng	Autu-mn
PhD Project Description										

[1]Doran, George T. "There's a S.M.A.R.T. way to write management's goals and objectives, Management Review, Nov 1981, Volume 70 Issue 11

One Publication Paper										
One Publication paper										
One Publication Paper										
One Publication paper										
The trial Lecture										
One publication paper										
PhD Thesis										
PhD Thesis Defense										
Course works										
UNIK9290										
IKT715										
UNIK9700										
EX602										

4. Planned stays outside of Norway

Indicate plans, if any, for periods at other research institutions etc. abroad (institution, country, purpose, time span, funding, etc.):

This research will be done jointly in Rwanda and Norway: 9 months and 3 months respectively each academic year.

5. Intellectual property right restrictions

Indicate if there are any intellectual property right restrictions (copyright, etc.) on the dissertation in order to protect the third-party interests: ❑ Yes [X] No

If yes, elaborate:

6. Infrastructure

Indicate infrastructure requirements for the PhD project (office space, computer equipment, special equipment, etc.):

- A few mesh routers and Micro-PCs and a few internet cables.

7. PhD project description

7.1 Background

The Kigali Institute of Science and Technology is running an e-learning project which calls for a move from the one-room schoolhouse to the one-world schoolhouse. With the understanding, Rwanda has initiated a project of one laptop per child and would like to implement the open learning framework. The challenges to Internet availability, however, is mainly based on that terrain in Rwanda and her neighborhood in the east Africa, is very complicated because of the very steep mountains, a number of natural forests and wetlands. This natural beauty can provide natural challenges in providing rural residents high speed and seamless Internet services. [1-4].

The Rwanda Utilities Regulatory Agency (RURA) works to achieve Universal Access with the core objectives to contribute to lower prices for Internet capacity and ICT application, all looking forward to extend the geographic reach of ICT applications in rural and urban poor communities in the country. There is a belief that the national fiber-optic backbone network might be available at low-cost for use in the telecommunications sector all over the country. Under this, it is expected that the roll out of Wireless broadband WiBro will ensure seamless internet access around Kigali and other cities of Rwanda [4], but I think this kind of Internet connectivity would take years to reach to the rural villages, notably the vicinity of Rwanda because even if those challenges are noticeable, "Rwanda has the 4th fastest internet in Africa and currently relies on three submarine fiber optic cable systems for Internet connection such as the East Africa Submarine Cable System (EASSY), the East African Marine Systems (TEAMS) and SEACOM through local telecommunication companies and ISPs " [1].

It is with these evidences that I think wireless mesh networks would bring a lot of answers to the Internet connectivity in Rwanda and neighboring local villages of East African Community. WMN will certainly help connect rural schools, institutions, firms and numerous rural households to the internet in a tolerable cost techniques and will be supportive to the objectives of optical fibers and Internet connectivity to the big cities like Kigali, Bujumbura, Kampala, Nairobi, etc.

7.1.1 Motivation: The need for Internet connectivity

Having found out that Internet connectivity is a key enabler for new businesses, for future professionals to achieve a high level of competence in their work and for efficient public sector, the Internet, mobile telephony and portable computers let today's user meet novel applications provided by service developers, who are motivated by the popular customer trends in technology. Knowing that the supply-demand chain observed in telecommunications causes the complexity of both the user devices as well as the network to increase; the complexity being caused by the need to support quality of service (QoS), security and mobility for the new services throughout the heterogeneous communication network [5]; the target with the present project is to optimize the availability of Internet connectivity and cost by

allocating the network resources in such a way that the speed of the network in question is maximized, at the tolerable cost. In order to achieve this targeted objective, the intelligence level of the network must be increased by decision engines, which may continuously collect information from the network, classify and store it in a repository to be queried by their peers. In this case, the Internet can become a tool for emerging economies since it is applied in a way that addresses the challenges of improving the lives of the least-privileged rural villagers and most-needy millions around the world.

7.1.2 Problem Statement

In rural area and in small towns of East Africa, notably in Rwanda, there is a problem of Internet connectivity and its QoS like problems in the high-quality real-time services such as Voice-over-IP, video streaming, competitiveness of packet-based TCP/IP networks, etc. Therefore, the Internet connectivity does not only cost very high but also is not available to satisfy customers who really have money! Thinking about the potential solutions, the deployment of wireless mesh networks (WMNs) may work to solve the problem; however, with a couple of challenges.

The main research question is: *"How can we improve the performance of a WMN or/and how can it be improved in its performance by the careful network strategic designs and efficient plannings so as to satisfy the needy rural villages in Rwanda and her surroundings at a tolerable price?"*

7.1.3 Research objectives

Bearing in mind that wireless mesh networks have existed for a certain time, the main objective of this study is to ensure the QoS and reliability of a multi-hop wireless network by mastering the routing techniques and scheduling algorithms, enhancing the minimal cost of Internet connectivity. Under this objective, the study of Media Access Control (MAC) layer is necessary.

MAC layer is located above the physical layer; it provides logic information channels to wireless data link layer. It defines delivery support to voice, video and authentic data and plays an important role in the limited wireless bandwidth sharing. The major routing objectives will be to *controlling network data flow*, *determining the status* of the sending and the receiving nodes, *identifying the best or optimal route* to transmit data, *reducing transmission delays* and related errors, *preventing the overuse* of a particular route or node, thesse routing objective must be mastered and practiced in C++ programme compiler.

This will end up with the deployment of acertain wireless mesh network system, testing it and doing a few measurements on it, all being around the headquarters of the University of Agder. In such a wireless mesh network to be deployed, the quality of Services (QoS) in the Internet connectivity must be excellent.

7.3 State-of-the-art

Wireless mesh networks emerge as a flexible technology, a low-cost and multi-purpose networking platform. A mesh network is a hybrid network, which consists of a mixture of fixed routers and mobile clients interconnected via access points.

In general, a wireless mesh network is composed of three components: access points (AP), mesh routers and mesh clients. Fig.1 illustrates the architecture of a wireless mesh network.

Different from a traditional ad hoc network, which is an isolated self-configured wireless network, the mesh network architecture introduces a hierarchy with wireless routers communicating between mesh clients and APs. A typical wireless mesh network usually has 30 to 100 mesh routers. The fixed APs are wired to connect to the Internet to provide high-bandwidth connections to the Internet backbone. The meshing among wireless routers and APs creates a wireless *backhaul* communication system. The backhaul provides each mobile client with a limited number of entry points connected to the Internet.

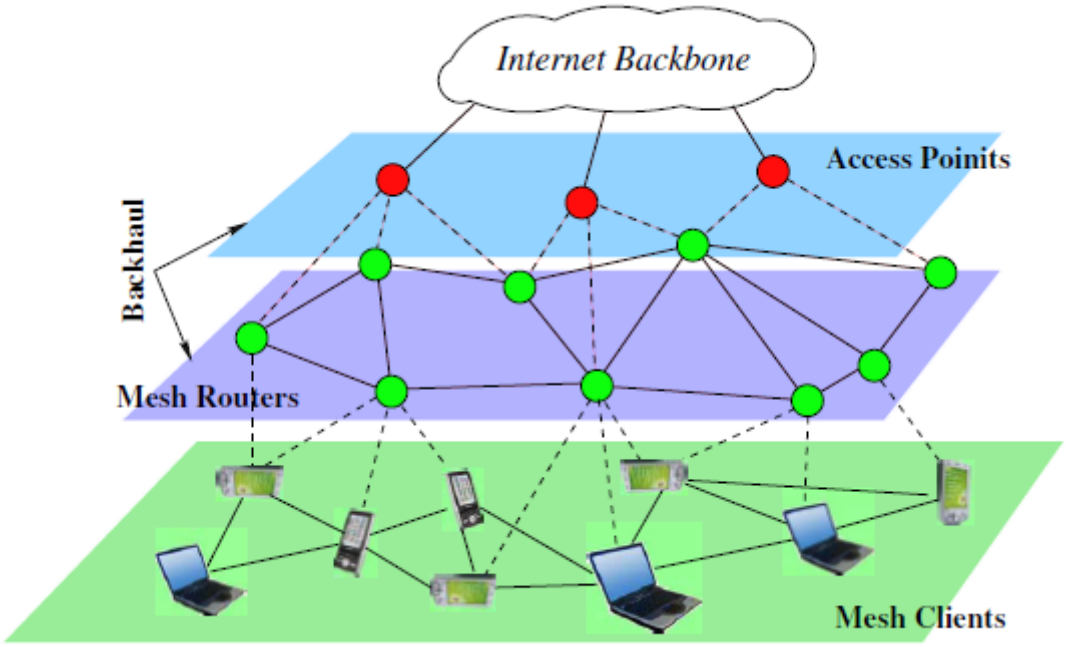

Figure 1: Architecture of a wireless mesh network [6].

These entry points, along with the APs, are usually referred to as *Hot Spots*. As the middle layer between the APs and mesh clients, mesh routers must cover all these hot spots. Mesh clients have more varieties of devices compared to mesh routers. These devices can be laptops, tablet PCs, PDAs, IP phones, RFID (Radio Frequency ID) readers, BACnet (Building Automation and Control networks) controllers, and many other types of widely used wireless devices.

The WMN technology shall be the main focus of this PhD research project because it has promissingly emerged in providing economical and scalable broadband Internet accesses. In WMNs, there are mesh routers and mesh clients. The mesh routers, which are generally stationary, are connected in an ad hoc manner to form a network backbone. A subset of them could be equipped with gateway functions so as to link the mesh networks to the Internet. The mesh clients can therefore access the Internet through the

mesh routers. In mesh networks, it is very cruitical to maintain network activities for a long lifetime with high energy efficiency. As more and more outdoor applications require long-lasting, high energy efficient and continuously-working mesh networks with battery powered mesh routers; therefore, it is important to optimize the performance of mesh networks from a battery-aware point of view the role of traffic, thus, forecasting in QoS, routing becomes more prominent [7,8].

The challenges to the targeted seamless connectivity's QoS and economic aspects shall mainly be the energy-saving problem. To solve the energy-saving problem, the big role will be played by optimization algorithms for route discovery and establishment in this wireless mesh networks. The mesh network energy-balancing route scheduling algorithms will be implemented on side of a load-balanced switch. Greedy Algorithm, Back Tracing Algorithm, and some others in this category will be surveyed and utilized. These algorithms must consider both the traffic and the remaining power of all nodes. In addition, the shortest path is selected after such considerations to meet the delay requirement of many applications. The algorithm must compute an energy consumption balancing factor for each node, which can represent a balance of the traffic and the remaining energy of each node, this optimization of energy consumption through programming is refered to as Green ICT. Green-IT's objective is to reduce energy consumption, by making small changes to the ways computers and other electronic devices are utilized. We use several matrices to describe the relative information to make the decision, which makes the algorithm simple and efficient. The simulation must show good result for applicability [9-11].

Furthermore, wireless mesh network is an emerging technology that can reach to a seamlessly connected world into reality. By definition, a wireless mesh network is a peer-to-peer, multi-hop wireless network in which participant nodes or access points cooperate to route packets [12-14]. Wireless mesh networks is able to ensure connectivity of the entire cities very easily, effectively and using inexpensive existing technology. In a wireless mesh network, the network connection is spread out among dozens or even hundreds of wireless mesh nodes that communicate to each other to share the network connection across a large area. Mesh nodes are small radio transmitters that function in the same way as a wireless router. Nodes use the common WiFi standards known as 802.11a, b and g to communicate wirelessly with users, and, more importantly, with each other.

In summary the economic aspects of wireless mesh networks include:

- They rely on the same WiFi standards (802.11a, b and g) already in place for most wireless networks.
- They are convenient where Ethernet wall connections are lacking -- for instance, in outdoor concert venues, warehouses or transportation settings.
- Mesh networks are "self configuring;" the network automatically incorporates a new node into the existing structure without needing any adjustments by a network administrator.

- Mesh networks are "self healing," since the network automatically finds the fastest and most reliable paths to send data, even if nodes are blocked or lose their signal.
- Wireless mesh configurations allow local networks to run faster, because local packets don't have to travel back to a central server.
- Wireless mesh nodes are easy to install and uninstall, making the network extremely adaptable and expandable as more or less coverage is needed.

One of the primary benefits of whichever existing wireless network is the ease and convenience of connecting devices. Unfortunately, that ease of connectivity and the fact that the information is transmitted through the air will make the network vulnerable to interception and attacks. The prevention of eavesdropping has been the main focus of many network administrators [15].

To sum up, the innovative work with this research project lies onto the improvement of routing and scheduling algorithms looking forward to offering the seamless connectivity, the QoS and reliability in WMNs, with efforts to make connectivities available to the dansely populated villages and small cities in Rwanda and neighboring countries.

7.4 Potential research directions

Multi-hop wireless mesh network will continually be the main research topic and the study can be organized from layers' perspective as pre-planned below:

- The study of medium access control (MAC);
- Routing and scheduling algorithms for WMNs;
- Cross-layer solutions;
- Whenever needed, the object oriented C++ language will be the programming environment;
- Artificial intelligence and optimization techniques will be considered to improve the system performance during the process of designing.
- Design, simulation, implementation and testing of a multi-hop wireless mesh network must be the destination for this research work.

The rough areas from which journal and international conference publication papers will be taken will certainly come from the above mentioned areas. However, the additional sub-area might be for instance:

- A survey-research on green e-services for the emerging economies of Rwanda (in 2013);
- Simulation of Internet mobility in Rwandan Nyungwe National Forest (2014-2015);
- Economy-oriented optimization towards a congested multi-hop *wireless mesh* network system. Case Study: KIST's Wireless Internet. (2014, 2015, 2016).

7.5 Methodologies and step-by-step work flow

The research topics identified in sub-section 7.4 will be covered by the following step-by-step methodology:

- ***Step 1: Theoretical studies and Litterature review*** must be the an ongoing activity during the whole periode of this PhD project. This will emphasize on the comprehensive understanding about Wireless Mesh Network and Routing Protocols. The success with the planned course works and writing the given assignments in a scientific format can be classified under this step. As a result from this step, two concrete starting points will be specified: The course work will be entirely covered and the two papers will pass through, one being International Conference paper and another being a journal publication paper.
- ***Step 2: Digging deeper on the study of the Network layer of OSI Model*** . Studying the MAC layer mechanisms and looking at the layers that may use the Media Access Control (MAC) layer, which located above the physical layer. MAC layer provides logic information channels to Wireless Data Link layer. It defines the delivery support to voice, video and authentic data, and plays an important role in the limited wireless bandwidth sharing. The starting point will be theoretical study and the next step will be the study of routing and scheduling algorithms for MAC-layer within WMNs just for the cross-layer solutions.
- ***Step 3:*** The thorough study of the network protocol stack which typically has five layers: application, transport (TCP), network (IP), data link (including MAC layer) and physical layer [16-17]. The self study of C++ program compilation will be under this step.
- ***Step 4: The regular presentations in the PhD forums***. Topics will be taken from the main research area: Multi-hop wireless networks. This step is very important because it will enrich my research capability, especially on the way I will be evaluated by the audience and the way I will be answering to their questions, which will take me to the next step of implementation of ideas out of the PhD forums. Whenever an attempt to submission of an International conference paper or/and a Journal paper, I will first present its skeleton to our PhD forum audience so as to get their comments. I will make efforts to do this exercise at least once a year and at most twice a year; as a result, good papers will be structured.
- ***Step 5: Ten-to-twelve Micro PCs will be utilized for the purpose of deployment***, testing and measurement of a Multi-hop wireless Mesh Network system around the University of Agder. The multi-hop wireless mesh network system to be deployed shall be available for other laboratory works such as wireless security, wireless signal strength measurements, network mobility, etc. Thus, the wireless mesh network will be able to draw conclusions on service reliability and QoS, all making predictions regarding the destination and adapting its resource reservation strategies.

7.7 Expected Overall Results

Whenever the mentioned potential research directions and step-by-step flow of activities are achieved, the results from each mini-project will be published at PhD furums, then comments implemented for international forums such as refereed conferences or journals and finally a PhD dissertation will be structured. Released codes and technical reports will also be uploaded for the next generation's knowledge sharing.

8. References

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