Modeling IP-Based Powerline Network and Interconnections with Wireless Networks for Communication in Non-Urban and Low Density Areas of Developing Countries.

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Abstract---**The communications in urban areas have been researched for a long time and a number of solutions are available ranging from wire line to wireless technologies. However, the communications towards non-urban and lowly populated areas in some of the developing countries still is a problem. Different technologies have been proposed but still facing a problem because of few end users. This paper is proposing the use of PLC network and interconnects with wireless technologies at primary substation where enough traffic will be realized to be another alternative. The contribution has analyzed the communication through powerline network from customer premises with two regenerative repeaters and CSMA/CD MAC protocol to distribution transformer. The modulation used is direct sequence spread spectrum with binary phase shift keying. The coding is Bose Chaudhuri Hacknguem (BCH). From distribution transformer to primary router at primary substation contentionless MAC protocol of token bus is used. The wireless networks have been connected to PLC at primary router. Simulation results are presented.**

Index Terms-- **MAC protocol, Routers, CSMA/CD, Traffic Projection, VoIP, QoS.**

I. INTRODUCTION

The provision of the various services in an urban area is usually not a very big problem since a number of options are available ranging from wireless technology, LAN/MAN/WAN, wireline networks, optical fibre cabling and VSAT. Recently many authors have studied the technology viable for communication in non-urban areas and low density in different environment especially in developing countries, by reflecting the already available wireless technology adopted in some of urban areas of developing countries. These wireless technology are Cellular networks (GSM and WCDMA), VSAT, Microwave based wireless access, TETRA (Terrestrial Trunked Radio), Cordless (CT2, PHS, Digital European, Cordless Telephone (DECT), Integrated/Combined VSAT/WLL, Integrated/ Combined Microwave/WLL and proprietary Solution (eg. DaRT). All these technology differ in their basic capacity and coverage design. Technologies, which have realized to be the candidates for communications in such areas, are VSAT/Satellite systems. But according to the indications in various developing countries like Tanzania the project implemented using such communication media have been either failed to be implemented or those, which have implemented failed to satisfy the requirement of communication in such areas [1]. The reasons behind are the cost of infrastructure of the proposed technology due to few potential end users, hence causing the failure of communication in non-urban and low-density areas in developing countries [1].

Powerline network is the basic consideration, because the potential telecommunication end users first consider having electricity in their household and business areas or tends to implement the network from electrical power grid or private operators network. It has observed that about 10% of residences in Tanzania have managed to have electricity, while Tele-density is only 1.25. The researchers have already investigated the applicability of Powerline Network for communication in developed countries and already the possibilities of communication in such medium have been realized [2], [3]. The powerline networks have proved to have enough bandwidth for communication at any data rate. The limitations which is still hindering the communications through this media is the regulations by communication authorities in various countries, for example in Europe, CENELEC standard have been regulated the operation frequencies and maximum power to be transmitted in PLC environment [2]. The same applies to USA and Japan but differently from Europe, the Japan and USA PLC both frequencies and power operations are differently and also only frequencies have been regulated basing on radio operations frequencies. These have been caused the researchers to review the operations in PLC. The frequency band and maximum power to be operated is still under research in various countries, because PLC radiates like antenna and can cause interference to other communication medium if it operates under same frequency with for example wireless, normal broadcast radio and so on. The Powerline Networks implemented in different countries have shown to have similarities and this indicates to have a similar model. In Europe for example from households to distribution transformers the maximum distance is 500meters and in Africa it extends up to 1.2km to distribution transformer and up to 5.2Km to primary substation [4]. This in PLC environment is called last mile. PLC in principle is affected by noise, but this has shown to be similar with other communication channels like cellular and radio, this limits the performance to be achieved.

In developing countries the telecommunication regulators have not yet considered PLC as a transmission media and nothing have been done to regulate it for communications. But still various companies are operating locally. For example in Tanzania, Tanzania Electrical Supply Company (TANESCO) is communicating in Powerline network high-tension grid basing on CENELEC standard due to manufacturer of the equipment. Many researchers have already pointed out that IP based network is the cost effective solution for communicating towards non –urban and low density areas and technologies in consideration being satellite [1]. The reasons behind are data-networking equipment is easily available at competitive price, all links integrates data and voice packets on per link basis, enabling higher channel utilizations and Packets are acceptable even when network is busy [1], [4]. In addition in developing countries, powerline network is well established and where the network is not available can be implemented because the electricity has shown to be the basic requirement for development. According to the above-mentioned reasons this paper is proposing VoIP through PLC to be another alternative for communications from non-urban and low density and then interconnect with other operators at higher stage. For utilizing this type of media will enhance the communication operators to operate up to 5.2km through PLC and then interconnect to wireless. This can connect up to 28,000 end users in non-urban areas per primary substation in developing countries. In addition, this type of technology will make more customers to run for communication because the network will be within their disposal. Hence having many customers and cost effective technology of IP, which requires computer equipments, and also PLC, which not only have implemented purposely for communication but also for providing electricity will enhance the operators to invest and also to make profits.

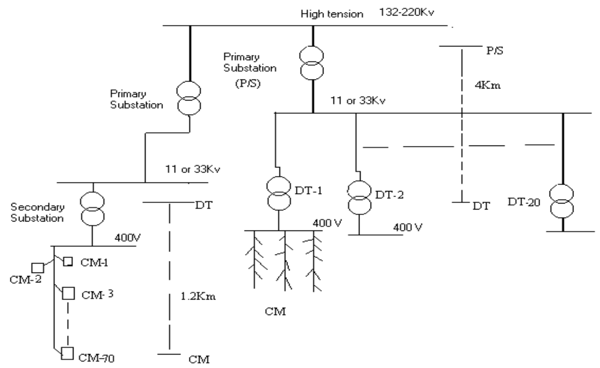


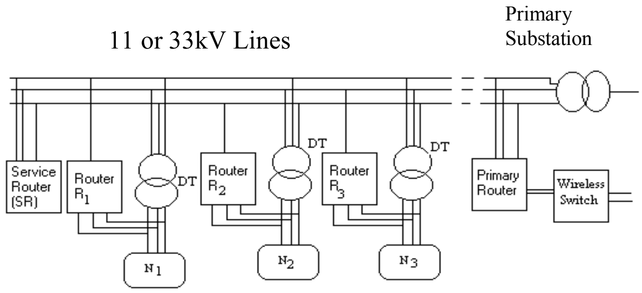
Fig. 1: Powerline Network layout

Figure 1 is a layout of powerline network in Tanzania. The parameter DT is a distribution transformer, which is maximum twenty. CM is customer meters, which are maximum seventy per phase [4]. This paper is giving the networking architecture of VoIP through Powerline network and interconnecting with wireless network.

Section two gives the general network concept from customer data switches to primary substation through bridging routers at distribution transformers. Section three presents the traffic projections and network modeling is explained in section four. Section five is the analysis and simulation results in section six. Finally the discussion of results is presented in section seven and conclusion in section eight.

II. NETWORK SETUP AND ARCHITECTURE

The study is carried out on area where electrical power supply network exist. Due to hostile environment and attenuation in PLC, the design of interface in consideration is direct sequence spread spectrum with Binary phase shift keying (BPSK). The coding used is Bose-Chaudhuri-Hacknguem BCH(31,11) and interleaved for overcoming attenuation in PLC and burst errors due to impulsive noise respectively, so that to attain distances of 400m and 4Km in low and high tension respectively towards primary router [4].



Key:
N1, N2, N3 : Subnets
R1, R2, R3 : Bridging Routers
SR : Service Router

Fig 2: Layout of Powerline Communication Network Interconnections of Different Routers Located at Distribution Transformers.

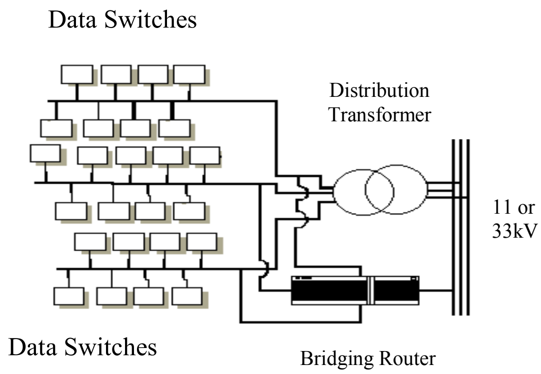


Fig. 3: Power-Line Network Layout from Customer premises to Bridging Router at Distribution Transformer (DT)

This makes to attain two hops from data switches to distribution transformers and total of three hops to primary substation, which indicates the actual viability of such network. Carrier sense multiple access with collision detection (CSMA/CD) have been considered for access part to bridging routers. From bridging routers to primary router part token bus have been considered.

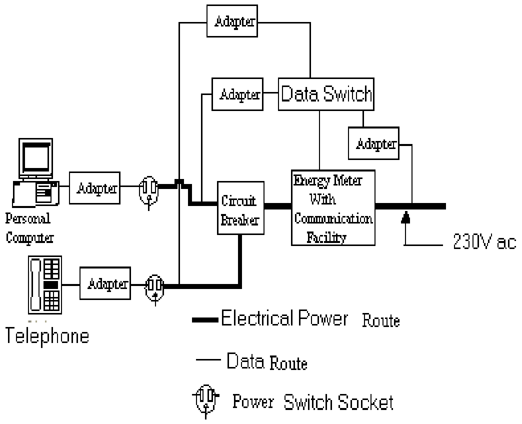


Fig 4: Layout of powerline networking in a Customer Premises

Figure 2 is a network layout for different sites, with N1, N2 and N3 subnets. SR is a service router for network reliability. Figure 3 shows data switches communicating with the primary substation side through the router at distribution transformer. Figure 4 shows a powerline connection in a customer premise, which consists of a telephone, a computer and an energy meter communicating through a data switch. The data switch is interfaced to power line through coupling circuit (adapter). Incase of failure in any phase of high voltage grid, data from bridging routers can be routed through SR. The primary router is installed on the primary substation side to provide connection to wireless network and receiving data from other bridging routers.

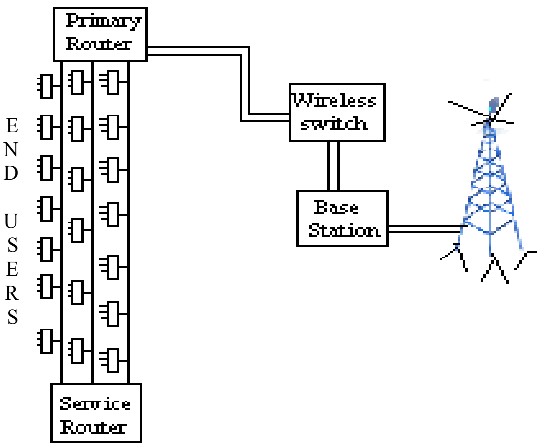


Fig 5: Networking substations with wireless network

Figure 5 shows the integration of power line data network and wireless networks. Studies have shown that in some developing countries up to 28,000 households are served by single primary substation. Therefore, the routers at primary substation should be able to serve approximately 28,000 data switches at households. To be able to provide such services over PLC, especially providing packetised voice traffic, number of queuing delay assessment for voice to meet quality of service (QoS) must be addressed.

III. TRAFFIC PROJECTIONS

The voice traffic is estimated using two states talkspurt and silence measurements [5]. The voice call has two states talkspurt, which are the call information period and silence period with no call information. Based on Brady's measurements adopted to project voice activity factor (probability of finding voice data), talk spurt = 1.2s and silence =1.8s. Also the call frequency of 1 to 10 calls/week as proposed by [1], for seven days a week and 24 hours a day have been considered. These are based on investigations of call rate made in various areas in developing countries. Data call rate is estimated as 1 to 10 calls a week as for 24-hours per day, and a holding time of 5 minutes. These are used to determine traffic in erlang; these are based on investigation of data call made in various areas in developing country. The traffic figures calculations have been performed as [4]. Considering the ON/OFF behavior, the probability of the data going through is given by equation (1).

$$p = \frac{\frac{1}{\lambda}}{\frac{1}{\lambda}+\frac{1}{\mu}} = \frac{1.2}{1.2+1.8} = 0.4 \tag{1}$$

The number of packets generated (Np) per user within call holding time h_t is given by equation (2)

.

$$N_p = \frac{pxh_t(\sec)xR_b}{P_L} \tag{2}$$

$$= \frac{0.4x5\times 60\times 32\times 10^3}{512} = 7500\text{packets}$$

Voice traffic intensity generated per user is given by equation (3), Where λ_{voice} is call frequency per user.

$$\rho_v = \frac{\lambda_{voice}xN_p}{\mu C} \tag{3}$$

$$= \frac{10}{24x7}x\frac{7500}{74x10^3} = 0.00603282\ 0\text{Erlang}$$

The number of data packets generated (N) per user within data call holding time $h_{t\,data}$, assume that the activity factor for data is half the voice is calculated as in equation (4).

$$N_p = \frac{\alpha_{data}xh_{data}(\sec)xR_b}{P_L} \tag{4}$$

$$= \frac{0.2x5\times 60\times 32\times 10^3}{512} = 3750\text{packets}$$

Data traffic intensity generated per user is given by equation (5), where λ_{data} is data call frequency of the user, h_{data} is the average data call holding time, α_{data} is the activity factor (probability of finding the network having data), P_L packet length and Np is the number of packet generated.

$$\rho_d = \frac{\lambda_{data} x N_p}{\mu C} \tag{5}$$

$$= \frac{10}{24x7} x \frac{3750}{74x10^3} = 0.0030164\,0\text{Erlang}$$

The metering traffic have been calculated as [9], and is based on the required services to be included in metering design to overcome the problem faced by power utility companies in Africa countries. According to the investigated made in Tanzania with around 80% of its population living in villages, there are 83 districts with around 8,000 villages of which 10% have managed to be connected to PSTN network [8]. In the case of PLC network, it has been assumed that since the network is already in place and PSTN need to construct new network, 20% of power utility customer have been considered being connected for voice. In additional for data 10% have been assumed for being connected to powerline network for data. The equation obtained after considering all scenarios at data switch is as in equation (6).

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$$\rho_T = 2x0.2\rho_v + 0.1\rho_d + \rho_m \tag{6}$$

IV. DATA NETWORK MODELING

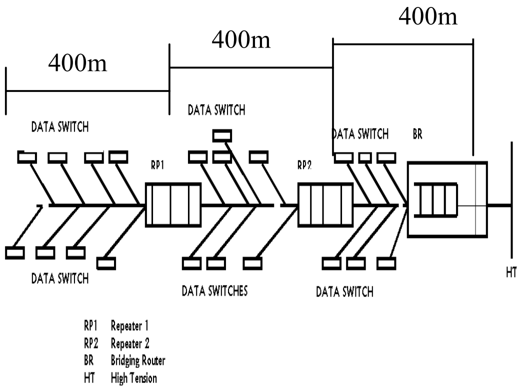

Fig 6: Two regenerative repeaters from customer premises

The delay analysis from data switch to bridging Routers has been modeled as shown in figure 6. Two repeaters have been placed in between as obtained in [9]. The voice packets generated during talk periods (talkspurts) are generated with exponential distribution with call rate $1/\lambda_v$ and service time $1/\mu_v$. The data traffic generated at a poison rate λ_v and service rate $1/\mu_d$. From the end users also the services rate was controlled by carrier sense multiple accesses with collision detection (CSMA/CD) to bridging routers.

Based on half duplex for data traffic and full duplex for voice Time Division Duplex Mode (TDD), traffic intensity in erlang (link utilization) ρ at given distance is given by equation (7). Where $N_{\max}$ is the maximum number of end users per phase, (d_r) is the distance where the repeaters is located and 1200 meters is the maximum distance from farthest data switches to bridging routers.

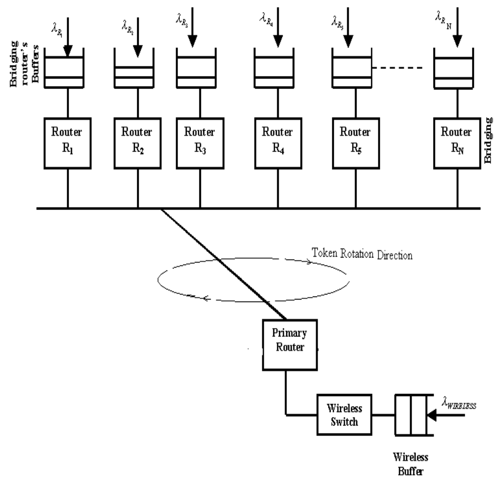

Fig. 7: Cyclic Model for correcting data from different stations at DT Routers.

ρ_T is the traffic intensity per data switch. The cyclic model shown in figure 7 has been used to collect data from bridging router stations to the wireless network. The services are the same as cyclic services but holding time dependent. At the wireless network erlang C model have been used to determine the queueing delay at this stage. The traffic at bridging routers has been calculated as in equation (8).

$$\rho = \frac{N_{\max} d_r}{1200} \rho_T \tag{7}$$

$$\rho_{BR} = \frac{d_r}{1200} \rho \tag{8}$$

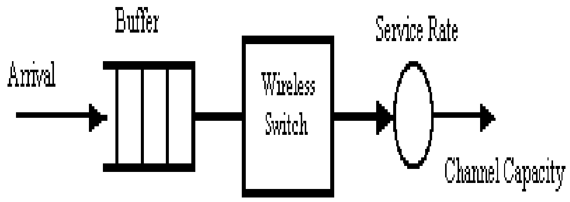

Fig 8: Model at the interconnection of PLC and wireless

V. ANALYSIS

The traffic figures may be used to determine the required capacity and subsequently the delay analysis in the network.

Equation (9) is the delay equation from data switches to bridging routers t_{DSBR}. The parameters t_{RP1}, t_{RP2} and t_{BR} are the delay to regenerative repeater 1, 2 and bridging router respectively. Equation (10) is representing the cyclic equation derived from cyclic model represented in figure 7. The parameters λ is the arrival process at each distribution transformer router, ρ_L is the packet length, R_{b2} is the data rate at high-tension bus, T is the token rotation time, t_{prop2} is the propagation delay. Equation (11) is the erlang C equation used to model the capacity of the required wireless switch, parameters A is the traffic intensity in erlang and it is assumed to be equal to the traffic at each bridging routers. H is the holding time and is assumed to be equal to 5 minutes for both data and voice. N is the number of trunks (channels).

$$t_{DSBR} = t_{RP1} + t_{RP2} + t_{BR} \tag{9}$$

$$t_{d2} = \frac{Tr}{1-\lambda T} + \frac{P_L}{R_{b2}} + t_{\mathrm{Pr}op2} \tag{10}$$

$$\mathrm{t}_{\mathrm{d3}} = \Pr[delay > 0]\frac{H}{N-A} \tag{11}$$

$$t_{DSRTDS} = t_{DSBR} + t_{d2} + t_{d3} \tag{12}$$

The total required delay equation used to realize the required capacity is as shown in equation (12). Through out it has assumed the packet length at each router to be constant.

VI. SIMULATION RESULTS

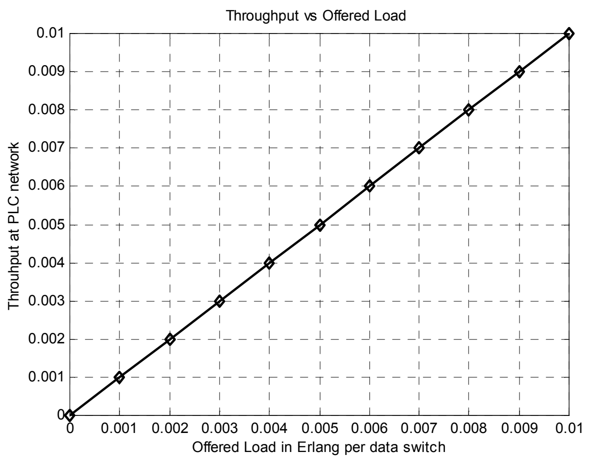

Fig 9: Offered Load Vs throughput of CSMA/CD

Figure 9 shown offered load against throughput of CSMA/CD, from projected traffic of 0.006erlang, which have been obtained per data switch (per user), the throughput is 0.006erlang. This throughput is the data, which will be obtained at the powerline channel bus per data switch. Figure 10 shows the variation of offered traffic load against queueing delay at the wireless network. It can be observed that at offered load, which have been obtained from projected traffic.

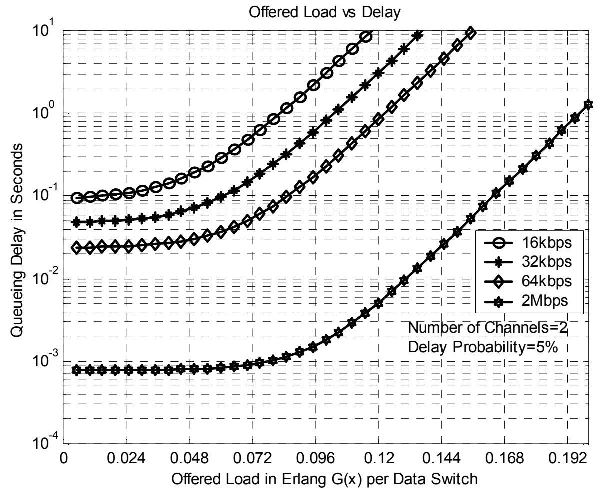

Fig 10: Model at the interconnection to wireless

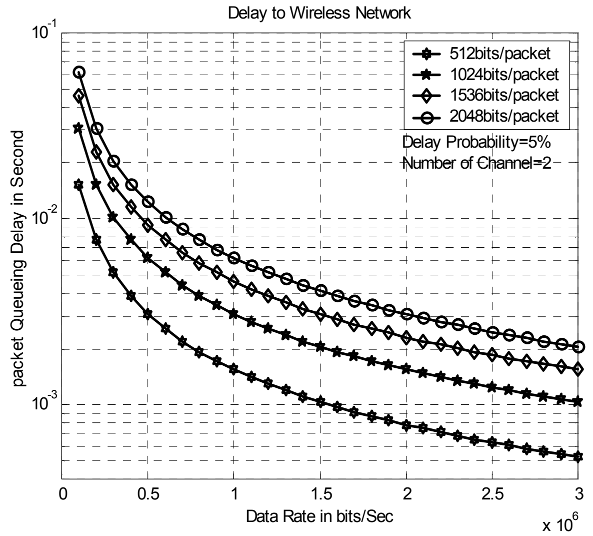

Fig 11: Queueing delay analysis v/s data rates with different packet length.

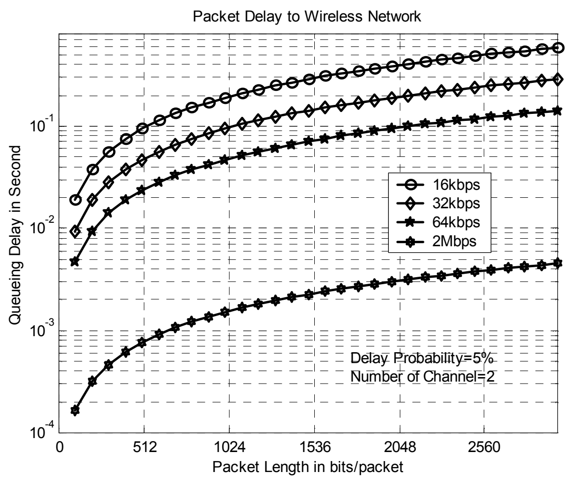

Fig 12: Queueing delay analysis v/s packet length with different data rates

of 0.006erlang, 2-channel and delay probability of 5%, the queueing delay is 0.8mSec, 20mSec, 50mSec and 100mSec at data rate of 2Mbps, 64kbps, 32kbps and 16kbps respectively. Figure 11 is the queueing delay against data rate at different packet length. It can be observed that for example at 2Mbps the delay is 0.8mSec, 1.5mSec, 2.5msec and 3mSec at packet length of 512bits, 1024bits, 1536bits and 2048bits respectively. Figure 12 is the packet length in bits/packet against queueing delay in second. It can be observed that at packet length of 512bits/packet the queueing is 0.8mSec, 25mSec, 50mSec and 100mSec at data rate of 2Mbps, 64kbps, 32kbps and 16kbps respectively.

VII. RESULT DISCUSSION

From the results obtained it can be observed that at a data rate of 16kbps the delay is imaginary to meet the required quality of service (QoS) for voice over Internet protocol (VoIP), which is maximum 100mSec or 0.1Sec. At higher data rate of 2Mbps the delay is within the required VoIP which indicate that the technology of interconnecting powerline network with wireless network at primary substation of power utility is a viable technology. Hence, it indicates that powerline network can be used as alternative technology for communication to non-urban and lowly density of developing countries like Tanzania, if telecommunication regulators will select appropriate frequency, which will overcome the interference of such media to other communications. To minimize the delay, which will be encountered due network behaviour the techniques proposed by IETF such as MPLS, DiffServ and others might be used to reduce the delay for VoIP[7].

VIII. CONCLUSION

In this paper the use of PLC for alternative solution for providing services to non-urban and low density and also interconnecting with wireless network have been modeled. It has been realized that PLC can be used as another alternative for communications in such areas. In addition still the network have identified to experience queuing delay at low data rate. Therefore different techniques proposed by IETF have been proposed.

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Biography

Justinian is a graduate with BSc Engineering (EE) from University of Dar es Salaam, which he received in 1998. After working in the industry for two years he joined again University of Dar es Salaam as Master student working on investigation of appropriate technology for remote monitoring of electrical power consumption in Tanzania. To date Justinian is preparing Phd proposal of utilizing powerline network for broadband access in non-urban areas and lowly populated areas.