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Performance Improvement of MAC Protocols for Broadband Power-Line Access Networks of Developing Countries: A Case of Tanzania

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***Abstract*—**This paper investigates the possibility of improving throughputs of some Media Access Controls protocols such as ALOHA, slotted ALOHA and Carrier Sense Multiple Access with Collision Avoidance with the aim of increasing the performance of Powerline access networks. In this investigation, the real Powerline network topology in Tanzania located in Dar es Salaam City, Kariakoo area was used as a case study. During this investigation, Wireshark Network Protocol Analyzer was used to analyze data traffic of similar existing network for projection purpose and then the data were simulated using MATLAB. This paper proposed and analyzed three improvement techniques based on collision domain, packet length and combination of the two. From the results, it was found that the throughput of Carrier Sense Multiple Access with Collision Avoidance protocol improved noticeably while ALOHA and slotted ALOHA showed insignificant changes especially when the hybrid techniques were employed.

***Keywords*—**Access Network, ALOHA, Broadband Powerline Communication, Slotted ALOHA, CSMA/CA and MAC Protocols.

I. Introduction

BROADBAND Power Line (BPL) provides an emerging alternative to conventional methods of obtaining high-speed Internet access due to its ability to cover wider area and more subscribers than any other method currently in use especially in developing countries like Tanzania. Moreover, operational costs and expenditure for realization of new telecommunication networks are highly reduced [1], [2]. Therefore, this technology promises cost effective method of broadband services provision in developing countries. However, channel utilization is still a challenging factor affecting the growth of this technology. Based on the results reported by [1], [3], it was pointed out that Broadband services through a Powerline access network of Kariakoo, Dar es Salaam can be realized with Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) as MAC protocol with a channel utilization of about 31%. The channel utilization is found to be less impressive and is threatened by the growing speed of communication technology especially for real time video communication which demands high capacity. For this reason, performance improvement techniques of this Powerline network as shown in Fig. 1 are urgently needed.

This paper investigates the possibility of increasing performance of the Powerline network by increasing MAC throughput of the given network.

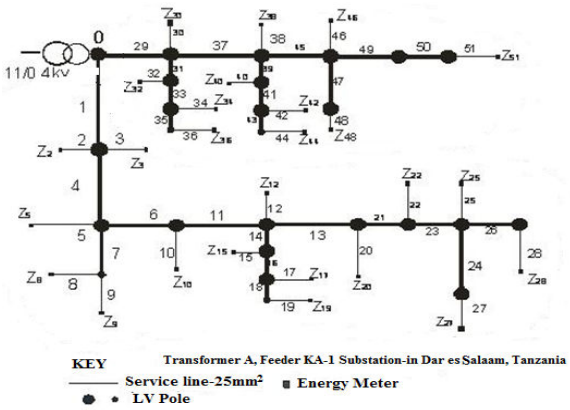

Fig. 1 Power-line network configuration of Kariakoo, in Dar es Salaam used as case study [4]

II. Merits of Power-line Access Network

Access networks are very important for network providers because of their high costs and the possibility of realization of a direct access to the end users/subscribers. Lately, about 50% of all investment in the telecommunications infrastructure is needed for the realization of telecommunications access networks [5], [6]. However, the access networks connect a limited number of individual subscribers, as opposed to a transport communication network. According to [5] and [7] the maximum number of end users/subscribers per phase in a Powerline access network is 70. Therefore, Powerline access network is a vital part in a communication system and hence an efficient way of utilizing it is unquestionable.

Network providers try to realize the access network as low cost as possible to increase their competitiveness in the deregulated telecommunications market. In most cases, access networks are still the property of incumbent network providers. Because of that, new network providers try to find solutions to realize their own access networks. A promising possibility for the realization of access networks is offered by the Powerline communications (PLC) technology. The other methods used to realize the access networks include:

- Wireless access networks
- Satellite systems

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- New cable/fiber-optic networks

The first two techniques seem to be expensive and are unable to offer higher transmission rates. On the other hand, building new cable or optical networks cause higher costs as well and takes a longer time. Therefore, the use of existing infrastructure seems to be a favorable solution [3].

In spite of having a number of GSM cellular mobile companies, fixed telephone lines, public data networks and various Internet Services Providers, Tanzania has a low teledensity for both mobile and fixed line. But Powerline network which has enough capacity to support communication services has gone farther in terms of coverage compared to other existing networks [8], [9]. This observation tells that BPL network is the best solution for realizing the access network as it is capable of reaching more end users/subscribers, since it covers wider area than any other network currently in use. With BPL the operational costs and expenditure for realization of new telecommunication networks are highly reduced. Consequently, this will tend to minimize the subscription cost to the end users/subscribers. From the mentioned advantages including, the cost, installation time and penetration capability, it is evident that Powerline network is the promising solution towards the realization of telecommunication access networks for broadband services provision in developing countries like Tanzania.

III. Proposed Performance Improvement Techniques of MAC Throughput

A. Creating Two Collision Domains in the Network

A collision domain refers to a physical network segment whereby data packets can collide with one another when being sent down a shared medium. Network collision occurs when more than one user attempt to send a packet on a network segment at the same time. To reduce the effect of collision, this work proposed to subdivide the network segment into two collision domains as shown in Fig. 2. This means that, the number of competing stations in the network will be reduced to nearly half the initial value.

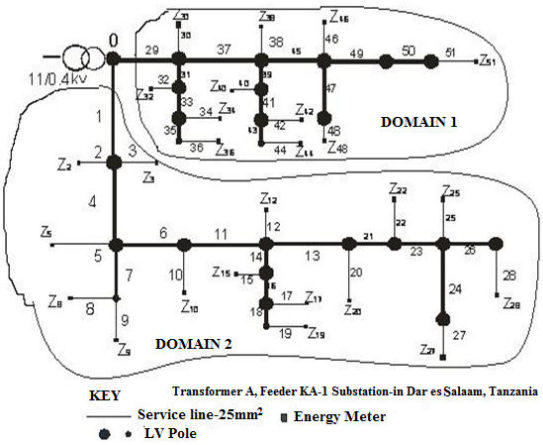

Fig. 2 Powerline Network with Two Collision Domains

B. Increasing Average Packet Length

The second approach suggested by this work on improving the performance of the MAC protocols is varying the average length of the data packet. From mathematical representation of the MAC throughputs of ALOHA, slotted-ALOHA and CSMA/CA [1], [3], [10]-[13], the throughput is also a function of length of the data packet as in (1):

$$G = \frac{\lambda P_L}{C} \tag{1}$$

In (1) the parameters, C, and P_L are the traffic load, the arrival rate, channel capacity and average packet length respectively. Thus, when the packet length is altered, the traffic load changes and so is the MAC throughput, provided that other parameters remain constant. Therefore, the optimum performance of a given protocol can be achieved by varying the packet length of the data.

C. Hybrid Technique

The third performance improvement technique proposed by this paper is to combine the two abovementioned techniques (hybrid). That means, the network is subdivided into two collision domains and the average packet length is altered concurrently. In this case, both the number of stations and the average packet length are altered to maximize the MAC throughput.

IV. Traffic Load Estimation

Use In communication networks, data traffic estimation can be obtained satisfactorily through measurements, which can be done when the network in consideration is in place. If the network does not exist, two methods can be adopted. These are detailed itemized services study or use of similar network for projection [3], [7]. In this paper the later method was adopted. Using the data traffic obtained from the network of University of Dar es salaam (UDSM-NET) and then the traffic is projected for Kariakoo network (Fig. 1). As detailed by [3], the average values recorded by the Wireshark protocol analyser are:

- The arrival rate, $\lambda = 2093.7097\ packets/sec$
- The average packet length, $P_L = 347.443$ bytes

The data packet arrivals were assumed according to Poisson process and the channel capacity was considered according to [3] as $C = 14Mbps$. Then, the total traffic generated in the entire network is given in (1).

$$G = \frac{2093.7097 \times 347.443 \times 8}{14 \times 10^6}$$
$$\therefore G = 0.415682\ Erlang$$

By the time traffic measurement was carried out, UDSM-NET comprised of 75 buildings [14], [15]. Suppose that the traffic is evenly distributed in the UDSM`-NET, then the traffic generated per station, ρ_c will be:

$$\rho_c = \frac{G}{N} = \frac{0.415682}{75}$$

$$\rho_c = 0.0055424\ Erlang$$

Since Kariakoo area is busy area with a number of offices and colleges/schools as in UDSM community, it was assumed that there will be a reasonable resemblance between the two networks in terms of traffic generation. It is assumed further that customers in Kariakoo network behave the same way as those in UDSM-NET, therefore, the same traffic type is expected in the networks and the traffic load per station can be assumed to be equal in the two networks. Then total traffic load in the network of Kariakoo with 51 subscribers will be as in (2).

$$G = \rho_c \times N_k \tag{2}$$
$$G = 0.0055424 \times 51 = 0.2826624$$
$$\therefore G = 0.28\ Erlang$$

V. Results and Discussion

A. Creating two Collision Domains in the Network

When two collision domains are created in the given network as shown in Fig. 2, the number of competing stations in the network will reduce to half the original value, say $N_k = 26$. Then, the throughput of CSMA/CA increases dramatically but those of ALOHA and slotted ALOHA decreases as depicted in Fig. 3. The MAC throughput of CSMA/CA when the number of stations is halved was found to be $8.136 \times 10^6 bps$ which is equivalent to the channel utilization of about 60%.

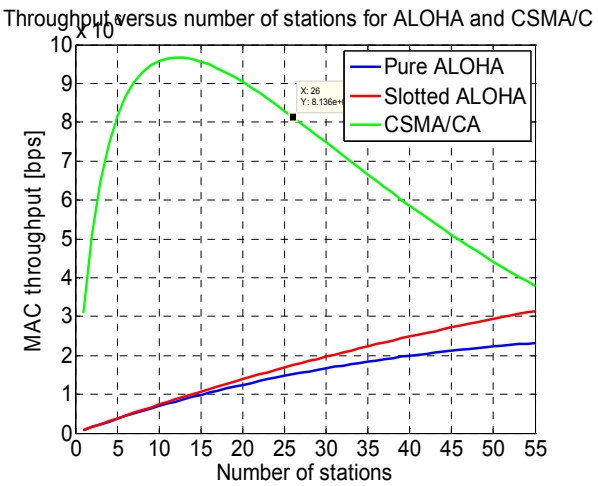

Fig. 3 Throughput against the Number of Stations

Based on the findings presented by [1], [3], the MAC throughput before and after the creation of two collision domains are compared in Table I.

TABLE I
MAC Throughputs Before and After Two Collision Domains

MAC Protocol	Initial MAC Throughput (%)	Final MAC Throughput (%)
ALOHA	15.99	11
Slotted-ALOHA	21.16	13
CSMA/CA	30.6	58

B. Increasing Average Packet Length

The performance of MAC protocols can be improved by proper increasing of the average packet length. Fig. 4 shows that the MAC throughput of pure ALOHA increases to $2.535 \times 10^6 bps$, which is about 18% utilization of the channel. The MAC throughput of slotted ALOHA increases to $2.845 \times 10^6 bps$ equivalent to about 28% of channel utilization and that of CSMA/CA is $5.776 \times 10^6 bps$ which is around 41% of the channel utilization.

The initial and final MAC throughputs are summarized in Table II.

TABLE II
MAC Throughputs Before and After Changing Packet Length

MAC Protocol	Initial MAC Throughput (%)	Final MAC Throughput (%)
ALOHA	15.99	18
Slotted-ALOHA	21.16	28
CSMA/CA	30.6	41

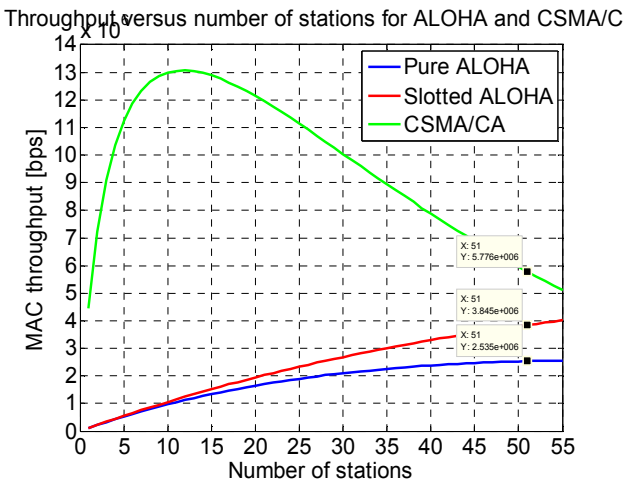

Fig. 4 Throughput against the Number of Stations when Packet Length Increased to 512B

C. Hybrid Technique

Creating two collision domains in the network and at the same time increasing the packet length of the data also gives positive result to the MAC throughput as illustrated in Fig. 5.

In this technique, the throughput of CSMA/CA is increased to $10.93 \times 10^6 bps$ which is equivalent to the channel utilization of about 78% while the other two protocols show no significant change.

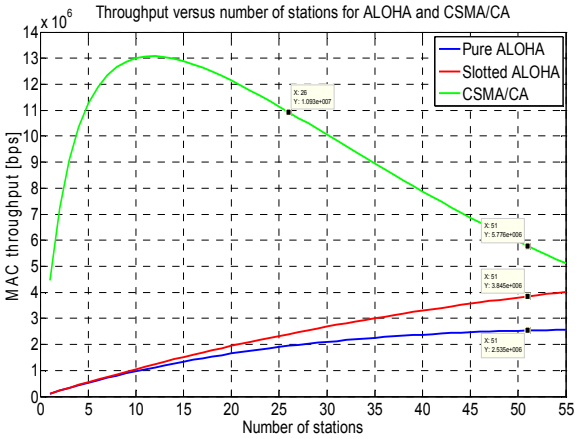

Fig. 5 Throughput Against the Number of Stations for hybrid Technique

The MAC throughputs before and after the hybrid technique implementation are summarized by Table III.

TABLE III
MAC THROUGHPUTS BEFORE AND AFTER CHANGING PACKET LENGTH

MAC Protocol	Initial MAC Throughput (%)	Final MAC Throughput (%)
ALOHA	15.99	14
Slotted-ALOHA	21.16	17
CSMA/CA	30.6	78

VI. CONCLUSION

The MAC protocols are responsible to orchestrate the data transmission in the network with the aim of reducing or avoiding collisions to maximize the network performance. Therefore, the performance of the MAC protocol dictates the performance of the network. This work tried to investigate the possibility of improving the performance of the MAC throughputs: ALOHA, slotted-ALOHA and CSMA/CA of the Broadband Powerline access networks. Out of the three improvement techniques proposed by this paper, the hybrid technique found to give the best result compared to the other two. Though there is a cost implication in implementing this technique as the network devices will double to handle the two collision domains. But the improvement made outweighs the cost of installing new network devices and therefore, the hybrid technique is suggested to be the appropriate performance improvement technique for the broadband Powerline access networks.

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