

# PERFORMANCE EVALUATION OF DIFFERENT MAC PROTOCOLS FOR IP BASED POWERLINE COMMUNICATION NETWORKS IN DEVELOPING COUNTRIES

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## Abstract:

This paper describes networking concept using powerline networks from end users to primary substation to support voice and data communications. Different MAC protocols which are contention and contentionless based such as CSMA/CD, Aloha systems, CDMA, TDMA and FDMA are analysed to identify which protocol is appropriate for data communication from data switches to Bridging routers at distribution transformers. Token bus is used to collect IP packets to primary router. Expected traffic load, Queueing delay and throughput are used to determine the required MAC protocol to support VoIP over powerline network.

Keywords: MAC protocol, traffic projection, VoIP, network modeling, duplex

## 1. Introduction

The powerline network from generation stations to end users is made of three main sections which are segment from 132-220Kv, 11 or 33Kv and 400V section as shown in figure 1. This paper describes the use of network from the end-users to primary substation to support

communication. In developing countries, this part of the network is constructed such that the separation between the adjacent conductors is much greater than the radius of the conductors. This makes the characteristics impedance to be different from those networks having less separation. From modeling already done, taking this factor into consideration, two hops have been realized from end users to distribution transformer. This hop distance is 400m in low tension and maximum distance to distribution transformer being 1.2km.

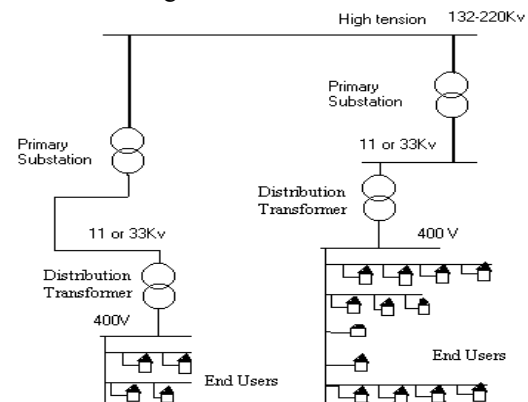


Fig 1: Powerline network layout

Due to hostile environment and attenuation in PLC, the design of interface in consideration

is direct sequence spread spectrum Code Division Multiplexing (CDM) with Binary Phase Shift Keying (BPSK). The coding used is Bose-Chaudhuri-Hocquenghem (BCH) and interleaved to overcome attenuation and burst errors due to impulsive noise respectively.

The duplex mode in consideration is half duplex and full duplex for data and voice respectively using time division duplex mode (TDD). The network in consideration is to bridge a distribution transformer between primary substations. A token bus protocol is used to collect IP packets towards the primary routers at primary substation. At the primary router other substations, PSTN and other wireless network will be connected. For traffic projections, a maximum number of power utility customers and a percentage of PSTN users, also talkspurt and silence behaviour of voice is used. For data traffic a percentage of power utility and PSTN data users have been used. Traffic due to value added services have also been considered. All these have been used to determine packet traffic in powerline networks.

Section two gives a general network concept from customer data switches to primary substation through routers at distribution transformers and H323 protocol, which interconnects packet data with PSTN also other switches which interconnects with wireless networks. Section three presents the proposed network parameters and traffic projections. The network modeling analysis is explained in section four. Section five is the simulation results. Finally is a results discussion and conclusion in section six.

## 2. Networking Concepts

Figure 2 is a network layout for five different sites, with N1, N2, N3, N4 and N5 subnets. SR is a service router for network

reliability. In case of failure in any phase of high voltage grid, data from bridging routers can be routed through SR. The routers R1, R2, R3 and so on are positioned at three phase distribution transformers.

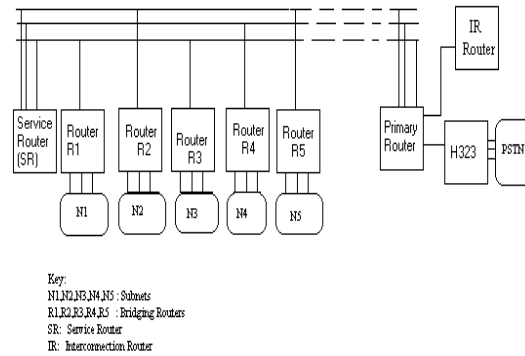


Fig.2: Layout of entire powerline networking

Figure 3 shows data switches communicating with the primary substation side through the router at distribution transformer. All data switches connected in three-phase form a single subnet (N).

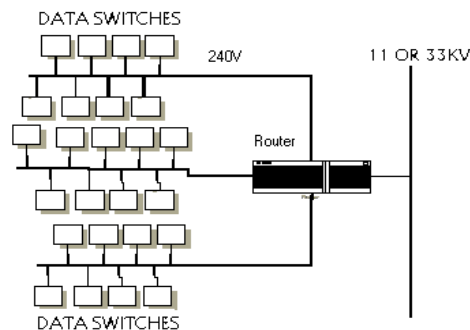


Fig 3: Layout of data switches at customer premises to Router at Distribution Transformer.

The primary router is installed on the primary substation side to provide connection to PSTN, wireless network, and other substations

also to control the entire network. Figure 4 shows the integration of power line data network, PSTN and wireless networks. 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) is addressed.

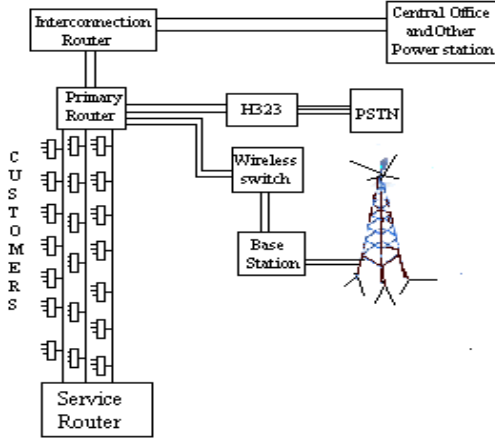


Fig. 4: Interconnection of primary substations, wireless and PSTN networks

### 3. Traffic Estimates and Calculations

In this study, the metering traffic estimates are based on [1] the traffic to be caused by the energy meter to combat metering problems faced by power utility companies [1]. For voice traffic, only about 10% of PSTN [2] customer can afford to be connected to this network, while for PLC, 20% of power utility customers are considered. This is based on the assumption that the power utility service is already in place compared to PSTN service whereby for a customer to have telephone facility, the PSTN network should be available. For the data traffic, only 10% of power utility

customers have been considered, because it will require customers to have computers. The traffic estimates have been used to predict the traffic handling capacity of each phase in a power line network. This in turn is used to predict call delay probability, because VoIP is sensitive to queuing delay [3]. Provision of the services considered a Bit Error Rate (BER) of  $10^{-6}$ , and delay of less than 100ms towards destination or circuit switched network. The voice is considered as synchronous voice services, normal Pulse Coded Modulation (PCM) of 32kbps and asynchronous data of 32 kbps for both up and down stream, duty cycle of 100%.

The voice traffic is estimated using two states talkspurt and silence measurements [4]. 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), talkspurt = 1.2s and silence = 1.8s. Also the call frequency of 1 to 10 calls/week as proposed by Chitamu [3] for seven days a week and 24 hours a day has 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 [3], 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 and the worst case of 10calls per week have been used in calculations. The arrival process and service rate for voice is considered as exponential with  $\lambda^{-1}$  and  $\mu^{-1}$  being talkspurt and silence respectively. Considering the ON/OFF behavior, the probability of the data going through is given by equation 1. The number of packets generated (N) per user within call holding time  $h_i$  is given by

equation 2. The parameters  $R_b$ ,  $P_L$ ,  $\mu$  and  $C$  are data rate, packet length, service rate and channel capacity respectively. Voice traffic intensity generated per user is given by equation 3, Where  $\lambda_{voice}$  is call frequency per user.

$$p = \frac{\frac{1}{\lambda}}{\frac{1}{\lambda} + \frac{1}{\mu}} = \frac{1.2}{1.2 + 1.8} = 0.4 \quad (1)$$

$$N = \frac{ph_i(\text{sec})R_b}{P_L} \quad (2)$$

$$= \frac{0.4 \times 5 \times 60 \times 32 \times 10^3}{512} = 7500 \text{ packets}$$

$$\rho_v = \frac{\lambda_{voice} N}{\mu C} \quad (3)$$

$$= \frac{10}{24 \times 7} \times \frac{7500}{74 \times 10^3} = 0.00603282 \text{ Erlang}$$

The number of data packets generated ( $N_d$ ) per user within data call holding time  $h_{data}$ , assume that the activity factor for data is half the voice is:

$$N = \frac{\alpha_{data} x h_{data}(\text{sec}) x R_b}{P_L} \quad (4)$$

$$= \frac{0.2 \times 5 \times 60 \times 32 \times 10^3}{512} = 3750 \text{ packets}$$

Data traffic intensity generated per user is given by equation 5, where  $\lambda_{data}$  is data call frequency of the user,  $h_{data}$  is the average data call holding time,  $\alpha_{data}$  is the activity factor (probability of finding the network having data).

$$\rho_d = \frac{\lambda_{data} N}{\mu C} \quad (5)$$

$$= \frac{10}{24 \times 7} \times \frac{3750}{74 \times 10^3} = 0.00301640 \text{ Erlang}$$

## 4. Network Modeling

### 4.1 Data Switches to Bridging Router

The delay analysis from data switch to bridging Routers  $t_{DSBR}$  is modeled as shown in fig. 3. Two regenerative repeaters have been placed in between at each 400m as obtained by [1].

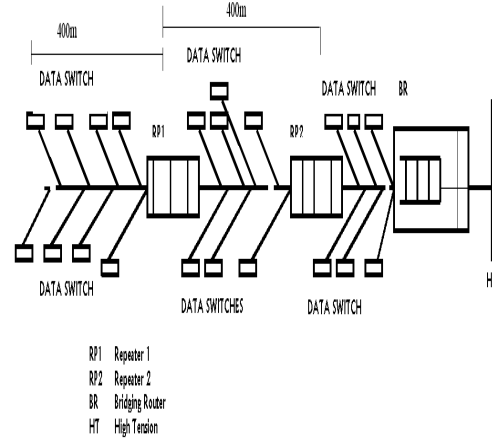


Fig. 5: Modeling of two hops from customer meters to bridging Routers in low voltage

$$t_{DSBR} = t_{RP1} + t_{RP2} + t_{BR} \quad (6)$$

The parameter  $t_{RP1}$  is the packet delay from data switches to the output of first regenerative

repeater,  $t_{RP2}$  is packet delay, from first to output of the second regenerative repeater and  $t_{BR}$  is the delay from the second regenerative repeater to the output of the bridging router. In each case the delay of each MAC protocol have been used in the analysis.

#### 4.2 Bridging Routers to Primary Router

At each distribution transformer the bridging router have been placed. In addition, another routers have been placed to the interconnections of PSTN, wireless and another substation network. The cyclic model used is shown in figure 6. Token bus has been applied whereby the service behaviour was equivalent with exhaustive model, but token holding time dependant.

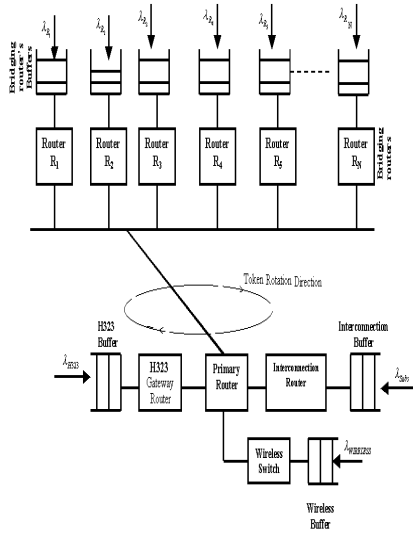


Fig. 6: Cyclic model for collecting data from Bridge Router.

On receiving the token the routers transmit the entire packets and those packets, which is

arriving until token expires. The delay is as given in equation 7.

$$t_{d2} = \frac{Tr}{1 - \lambda T} + \frac{P_L}{R_{b2}} + t_{prop2} \quad (7)$$

The parameter  $T_r$ ,  $t_{prop2}$ ,  $T$  and  $R_{b2}$  are token rotation time, propagation delay data transmission time from BR to PR and data rate in high tension respectively.

### 5. Analysis and Simulation Results

#### 5.1 Analysis

The traffic figures may be used to determine the traffic handling capacity of powerline network at acceptable delay probability as required by VoIP services. Data delay is not critical because data is not delay sensitive. Equation 8 is used to predict the delay from data switches to PSTN network where H323 protocol is used to provide the interconnection. In addition equation 9 is used for transmission delay analysis towards another substation.

$$t_{PSTN} = t_{DSBR} + t_{d2} \quad (8)$$

$$t_{sub} = (t_{DSBR})_{UPLINK} + 3t_{d2} + (t_{DSBR})_{DOWNLINK} \quad (9)$$

$$t_{DSRTDS} = (t_{DSBR})_{UPLINK} + (t_{DRDS})_{DOWNLINK} \quad (10)$$

Equation 10 is used to investigate the queuing delay from one end user to another within the same subnet. In each case for downlink stream broadcasting have been considered.

## 5.2 Simulation Results

Figure 7 gives the throughput of different MAC protocol at bridging router. It can be observed that pure Aloha will fail to serve the required data switches under projected traffic. In addition for stability of TDMA and FDMA will be able to serve 40 data switches whereby offered load is 1 erlang. The MAC protocols such as CDMA, CSMA/CD and slotted Aloha can serve the projected traffic. The delay analysis will be used to determine which MAC is better than other.

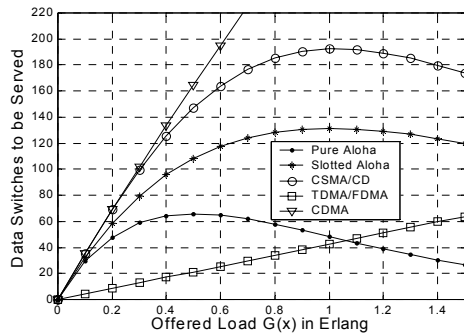


Fig.7: Throughput of different MAC protocol

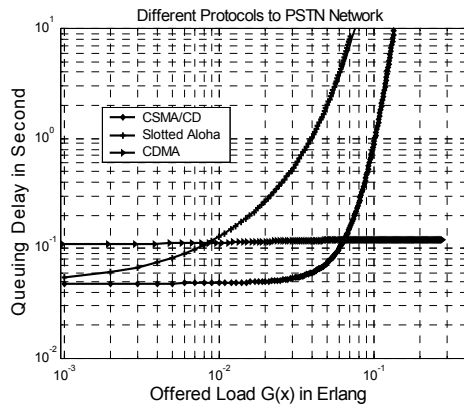


Fig 8: Queuing delay to PSTN network

Figure 8 is giving packets queuing delay to PSTN network. It can be observed that at light load all three MAC protocols can satisfy the required queuing delay of less than 100msec. As traffic load increases the CSMA/CD and slotted Aloha fails to meet the required performance. CDMA will serve the traffic at marginally of required performance. Figure 9 is the queuing delay within subnet network.

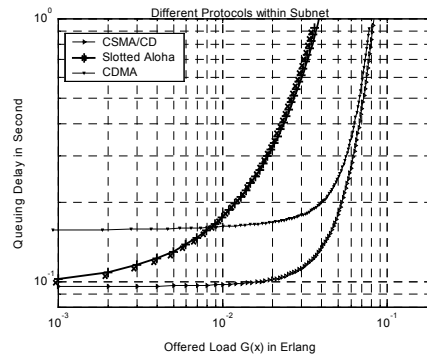


Fig 9: Delay within subnet Network

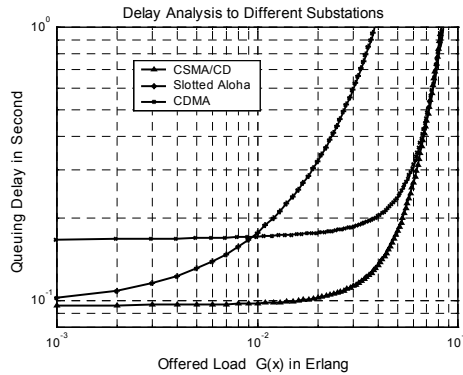


Fig 10: Queuing delay to different substation

At light load CSMA/CD have managed to provide the required QoS and at heavy load the CDMA have provided a better performance than others. Figure 10 is the queuing delay towards

different substation, the implementation of CSMA/CD at light load will meet the QoS but other MAC protocols cannot. Figure 11 is showing the performance of CSMA/CD under different data rates. It can be observed that the good QoS have been realized with increase data rate

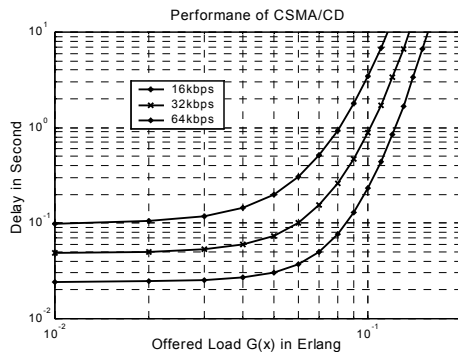


Fig 11: Performance of CSMA/CD under different data rate.

### 5.3 Results Discussions

The results, which have been obtained, indicate that all MAC protocols cannot give a better performance at heavy load in such networks. In order to be able to communicate in such networks data have to be transmitted at higher rate. In addition the protocols proposed by Internet Engineering Task Force (IETF) such as Diffserv and MPLS might be used to keep the queueing acceptable for VoIP [5].

### 6. Conclusion

In this paper the performance of different MAC protocols have been evaluated. It has been realized that CSMA/CD and CDMA are the MAC protocol to be used in such networks. In addition those protocols have failed to give the required performance. Therefore, different techniques such as IETF have been proposed.

### Acknowledgements

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