QoS and Performance of REMPLI PLC Network

Liping Lu, Raul Brito, Ye-Qiong Song

To cite this version:

Liping Lu, Raul Brito, Ye-Qiong Song. QoS and Performance of REMPLI PLC Network. 1st Workshop on Networked Control System and Fault Tolerant Control - NeCST Workshop 2005, Oct 2005, Ajaccio/France. inria-00000758

HAL Id: inria-00000758

https://hal.inria.fr/inria-00000758

Submitted on 16 Nov 2005

QOS AND PERFORMANCE OF REMPLI PLC NETWORK

Liping LU[1,2], Raul BRITO[1], YeQiong SONG[1]

1 – LORIA-INPL, Campus Scientique-BP239, 54506 Vandoeuvre-lès-Nancy-France
{lu,raul.brito,song}@loria.fr

2 – School of Mechanical and Electronical engineering, Wuhan university of technology,
430070 Wuhan, Hubei, P.R. China

Abstract: REMPLI uses MV and LV PLC network to establish a wide-scale distributed infrastructure for real-time monitoring and control of energy distribution and consumption. To satisfy the application QoS requirements, special QoS control mechanisms should be implemented in the PLC network for providing real-time access to resources at Master node. We propose flooding-based routing protocol as QoS routing mechanism and network dispatcher of Dual-Priority scheduling policy with deadline relaxation as packet scheduling mechanism. Our simulation results have shown that those QoS mechanisms guarantees minimum bandwidth utilization through periodic traffic and short end to end delay of aperiodic data request services.

Keywords: PLC, QoS, Master/Slave mode, routing, scheduling policy.

1. INTRODUCTION

Modern society demands a reliable and high quality energy supply. For the distribution utilities, it is substantial to maintain and improve distribution automation to provide power to customers at acceptable reliability level and to serve the customer in better ways. Building a secure and reliable communication system becomes more important to meet the demands and requirements of those applications at a lower cost. With the rapid dissemination of the Internet in recent years, optical fibers owned by power utility companies have been laid near distribution substation transformers in metropolitan areas, before these can be fully utilized; however, there is a need to develop an inexpensive, high-speed means of communication access for covering all customers meters and field equipments in the electrical distribution network.

The construction of private wire network costs much, since the energy metering and control equipments are distributed widely. On the other hand, there are the difficulties to access to certain equipments using wireless technology since they are often located in closed environments with metallic obstacles (reinforced concrete walls and tubes). In this situation, it is ideal to use the power line as a communication medium to construct an economic, secure and reliable communication system for at least the following reasons. No new wires are needed, resulting in low cabling cost. Reliable and high transmission speed PLC chips are now available for providing an efficient communication means. Power line is owned by the distribution utility for ensuring a certain level of security.

REMPLI[1] (Remote Energy Management via Power Lines and Internet) system uses Medium Voltage (MV) and Low Voltage (LV) power grid as communication media to implements wide-area, distributed control and monitoring, as well as remote customer meter reading. REMPLI PLC network should provide to applications (such as remote meter reading, remote device control, …) with QoS (Quality of Service) guarantees in terms of the data transfer needs such as reliability and delay (real-time).

In fact, PLC physical layer offers highly variable characteristics due to the time-variable noises injected by electrical devices. It is not easy to guarantee a certain bandwidth and maximum transfer delay. Moreover, in a wide area PLC network, transmitting a

---

[1] The project is carried out within the Fifth Framework Program of the EC (the project identifier is NNE5-2001-00825).

packet from a source to a not immediately reachable destination node requires the packet relay of the intermediate nodes (repeaters). However, considering the dynamic topology change and impossible prediction of the powerline attenuation, repeaters cannot be statically configured.

How to design QoS handling mechanisms for dynamically adapting the powerline circumstances and shortening the transmission time under stringent bandwidth limitation is presented in this paper. We propose a dynamic routing protocol for solving the repeater problem and a traffic dispatching policy for scheduling different priorities, providing guarantee of certain QoS to the application data, as well as ensuring a stable network management system. Then we present their performance in timeslot unit, as TDMA MAC protocol is assumed.

In section 2, we recall the REMPLI system architecture. The application services overview and their QoS requirements are presented in section 3. Section 4 presents QoS routing protocol and its performance. Then, a new scheduling policy is described and its performance is shown in section 5. Finally a brief conclusion is given in section 6.

2. REMPLI SYSTEM ARCHITECTURE

Fig. 1 shows a typical REMPLI system architecture. Application server is connected with the Access Point through the company's Intranet, based on a TCP/IP network. For the rest of network, the used network is PLC network. In PLC network, REMPLI Bridge spans from the MV segment to the LV segment. Each REMPLI Node connects with number of metering and/or SCADA field equipment, such as voltage measurer. For each of the voltage segments, there is the Master/Slave communication model. The Access Points and the Bridges are Masters for the MV and LV segments, respectively. The Bridges and Nodes are Slaves for the MV and LV segments, respectively. In this master/slave model, only master can initiate packet transmission. A slave has to wait until it is polled by its master to send packet back to the master. So in the whole REMPLI network there are as many independent polls as the masters as shown in Figure 1. In this paper, we focus on one master-slave model.

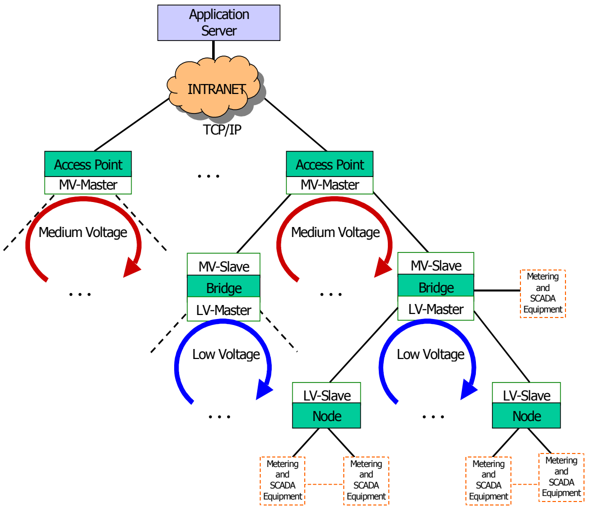

Fig. 1. Typical REMPLI system architecture

3. APPLICATION AND QOS REQUIREMENTS

3.1 Application Services

Applications use the REMPLI network to support services to the end-users of the application. These applications services can be divided into 3 types: metering services, remote control and monitoring services, and file transfer service.

<u>Metering Service</u> Provides customer meter reading collection or requested by non-real time applications, such as registration of energy consumption, energy loss detection, tariff management, billing, load prediction, etc. The customer meter reading collection is done by the application servers with periodic collection intervals range from about one second to one or more hours, even monthly. And the customer meter reading requested is an event-drive or human-drive demand to get certain customer meter data. Although the applications do not have strict timing constraints, the metering data should be transferred within a reasonable time (few seconds).

<u>Remote Control and Monitoring Services</u> Send commands to control devices and request the status or values of distribution components, equipment and devices. Those services can be used for EMS/DMS/SCADA applications. It requires two types of data transfers: routine (periodic) and on-demand (event-driven) data transfers. Required periodic update intervals range from about one second to one or more hours with required data delivery times that are less than the update intervals. Occasional data errors and late or missing data may be acceptable when the data user can recover on receipt of the next routine update. Event-driven data transfers upward and control information transfers (usually event-driven) downward are required to have data delivery times of less than 1 second (IEEETR 1525-2003).

File Transfer Service This service supports the transmission of a large amount of data (in the order of megabytes) through the network. For this type service, the transmission correction is more important than the transferring time. So it has the lowest priority, working as a background task, relatively to other services.

3.2 Network Management Services

Network management services permit to maintain and monitor a network, providing services such as logon and logout of nodes, configuration of PLC component parameters, status and liveliness of nodes, etc (Markus and Gerd, 2000).

These services can be considered both periodic (e.g. liveliness of nodes). This type service is very important to the network. It is the basis of the network running correctly.

3.3 Priority Levels in Network Layer

The Network Layer provides three priority levels: 0, 1 and 2 for aperiodic task and hard and soft levels for the periodic polling. The former three priorities are usually served for the application services. The latter two priorities are served for network management services.

The aperiodic priority levels are defined next, where a lower number means a higher priority:

- Priority 0 (CRITICAL), at Master side only.
- Priority 1 (EMERGENCY), at Master and Slave sides.
- Priority 2 (NORMAL), at Master and Slave sides.

Priority 0 is used for critical commands that should overcome any other priority. Since these commands don’t generate a critical response, this priority only exists at the Master side. Moreover, packets of this type should not lose its priority in favor of periodic packets. Priority 1 is reserved for emergency packets, and by internal management packets of the Transport Layer. Priority 2 corresponds to normal packets. By normal packets we refer all the traffic generated by the usual communication between Application Layers of Master and Slave.

Depending on each type of packets, the respect of periodic polling can be more or less strict. Due to this fact, we distinguish two types of periodic polling level: hard periodic and soft periodic. By hard periodic polling we refer to periodic polling that has stricter constraints relatively to the time period. Soft periodic polling adds a certain timing relaxations relatively to hard periodic polling. That is, if one deadline is missed, no major problem arises.

4. FLOODING-BASED ROUTING PROTOCOL

For avoiding statically configured repeaters, flooding-based routing protocol is considered in which all slaves should work as repeaters showing in Fig. 2. Therefore, in some timeslots, there are several repeaters to transmit identical information on the medium. The receivers could get the superposition of the signals. This technology is called single frequency network (SFN) explained in (Gerd, 2002). The flooding-based routing protocol is part of SFN.

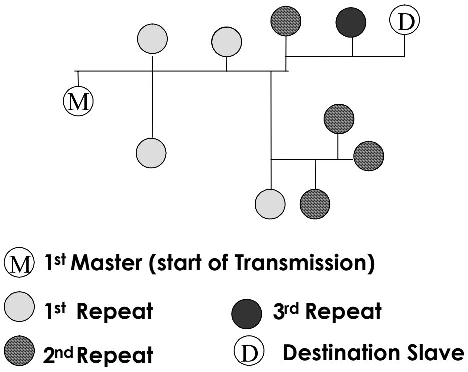

Fig. 2. Repeating in SFN

4.1 Protocol Description

Different repeater levels may be used in the downlink and the uplink, considering the powerline’s random channel characteristics. The table of the number of repeaters (called hereafter repeater level, represented as $r_{DL}(i)$ and $r_{UL}(i)$ for downlink and uplink) for reaching every slave (i) is stored in the master.

When a slave receives a packet correctly, it checks the packet header, and if the destination address is its own address or the remaining repeater level is zero, or the same packet is already transmitted once, it stops transmitting this packet, otherwise it continues to retransmit the packet by deceasing by one the repeater level.

When a master don’t receive the slave *i* confirmation within the maximum transfer time, a retransmission is required. Obviously the allowed number of repeater levels was not high enough. The master has no information if the transmission failed in the downlink or in the up link. To have a high probability, that the retransmission is successful, the master has to do:

$$\begin{aligned} r_{DL}(i) &= r_{DL}(i)+1 \\ r_{UL}(i) &= r_{UL}(i)+1 \end{aligned} \tag{1}$$

If the retransmission was not successful with new repeater levels, the master does (1) again and sends a next retransmission. This continues until:

- Successful transmission
- Maximum number of retries

- Upper bound for downlink repeater level and uplink repeater level reached.

In case of an overestimation of the repeater level, the protocol acts with more precaution to decrease the repeater levels for closing the real situation. There are two cases.

One case is that the retransmission leads that the downlink repeater level or uplink repeater level is more than the exactly needed. The destination slave *i* sets reserved bit, when it received the same packet ago or the repeater lever is not zero. The master looks up this bit to know that last failure happened in downlink or uplink from the successful slave confirmation packet after it sends a retransmission.

- The bit sets to 1. It means that the first request was successful and the failure happened on the up link. So $r_{DL}(i) = r_{DL}(i) - 1$.
- The bit unsets and the master receives the confirmation from the slave before the redefined time. It means that last failure happened in downlink. So $r_{UL}(i) = r_{UL}(i) - 1$.

The other case is that the transmission was successful without retry and the master receiving the confirmation from the slave *i* before the redefined timeslot. Decrement of the repeater level in the better PLC condition risks the retransmission which be caused by the insufficient repeater level in the other worse conditions. Moreover, the system shall react fast to changes of the channel. The fastest implementation is to count the number of continuing successful transmission since the last time, where respective repeater levels are necessary. When this counter crosses a configured number, the decrement is done. This counter is cleared when

- A decrement has done.
- A transmission failed.
- The master does not receive the confirmation before the redefined timeslot.

4.2 Performance

We focus the routing protocol performance on two metrics: average duration of a polling cycle and the average retransmission per a polling cycle. The former metric is defined as the time which the master polls once all the slaves. The formula to calculate it, is given in the following.

$$D = \sum_{i=2}^{n} \sum_{j=0}^{n_{retry\_i}} \left(2 \cdot (j+1) + r_{DL}(i) + r_{UL}(i)\right) \cdot T_s \quad (2)$$

Parameters:

n	number of node (master node with n=1)
T_s	duration of one slot for transmitting a packet
n_{retry_i}	retry number of node i
$r_{DL}(i)$	repeater level of downlink (i.e., master to slave) of node i for the fist transmission
$r_{UL}(i)$	repeater level of uplink of node i for the first transmission

An analytic approach is used to evaluate its performance for a set of common physical PLC topologies called "channel models" (Gerd, et al., 2005). Each channel model is represented by a matrix of PER (Packet Error Rate), where PER[i,j] is the packet error rate of the transmission between two nodes i and j. The result of the PER matrix is calculated by the physical layer emulator (Gerd, 2004). In this paper we assume that PER is a time-constant value. An example of PER matrix of *Np* nodes is show in Fig. 3. The first element of the matrix is defined as master, all others are slaves.

$$\left\{ \begin{matrix} 0 & \cdots & \cdots & PER_{M \to S_{Np-1}} \\ PER_{S_1 \to M} & \ddots & & PER_{S_1 \to S_{Np-1}} \\ \vdots & & \ddots & \vdots \\ PER_{S_{Np-1} \to M} & \cdots & \cdots & 0 \end{matrix} \right\}$$

Fig. 3. PER matrix

4 channel models are used, which are Ring_10, Ring_100, Rand_Area Np_20, Rand_Area Np_100, Rand_Area Np_200. The two former channel models have the topology of ring and the latter two have the topology of a tree with the master as the root and the randomly distributed slaves as leaves. The number in the channel model name indicates the number of the nodes.

The analytical calculation formula of the average polling duration $\bar{D}_{SFN}(i)$ for slave *i* is following:

$$\bar{D}_{SFN}(i) = \frac{\left(2 + r_{DL}(i) + r_{UL}(i)\right) \cdot T_s}{\Pr(i)} \quad (3)$$

$\Pr(i)$ is the probability of successful polling slave I with average repeater levels of downlink and uplink and without retry is:

$$\Pr(i) = \left(\sum_{r=0}^{r_{DL}(i)} \Pr_{Rcv,1}(i,r) \right) \cdot \left(\sum_{r=0}^{r_{UL}(i)} \Pr_{Rcv,i}(1,r) \right).$$

$\Pr_{Rcv,i}(s,r)$ is the first correct reception probability of slave *i* from the other slave *s* in timeslot *t* (*r+1*).

$$\Pr_{Rcv,i}(s,r) = \left(1 - \sum_{v=0}^{r-1} \Pr_{Rcv,i}(s,v)\right) \cdot \left(1 - \prod_{s' \in \mathbf{S} | s' \neq i} \left(1 - \Pr_{Tx,s'}(r) \cdot \left(1 - PER(s',i)\right)\right)\right) \quad (4)$$

And $\Pr_{Tx,i}(r)$ is the probability of transmission of slave *i* in timeslot *t* (*r+1*).

$$\Pr_{Tx,i}(r) = \begin{cases} 1 & \text{for } r = 0 \text{ and } i = 1 \\ \Pr_{Rcv,i}(s, r-1) & \text{for } r = 1 \\ \left(1 - \sum_{v=0}^{r-2} \Pr_{Tx,i}(v)\right) \cdot \Pr_{Rcv,i}(s, r-1) & \text{for } r > 1 \\ 0 & \text{else} \end{cases}$$

The average duration of a polling cycle is:

$$\bar{D}_{SFN,\Sigma} = \sum_{s \in \mathbf{S} | s \neq 1} \min\left\{\bar{D}_{SFN}(s)\right\} \quad (5)$$

Using above equations, we get the average duration in Table 1. The average duration is small, even 9.665 seconds for polling199 slaves. In Table 2, the simulation results show the flooding-based routing protocol of SFN has small retransmission time percent (<1.2%). So the flooding-based routing protocol is suitable for the powerline environment with the short small transmission time and less retransmission.

Table 1 Average duration of SFN

Channel Model	$\bar{D}_{SFN,\Sigma}$	Timeslot duration (s)	Average duration (s)
Ring_10	28.4	0.009792	0.278
Ring_100	419.1	0.009792	0.410
RandArea Np_100	380.5	0.009792	3.726
RandArea Np_200	987.1	0.009792	9.665

Table 2 Simulation result of average of packet retries per polling cycle

Channel Model	Average of packet retries per polling cycle
Ring_10	1,1%
Ring_100	0,4%
RandArea Np_100	0,5%
RandArea Np_ 200	1,1%

5. NETWORK DISPATCHER

The REMPLI PLC must also provide the mechanism to serve REMPLI applications differently in order to satisfy their different QoS requirements. The network dispatcher within the REMPLI system network layer of the master is a quality-of-service mechanism that plays an important role by permitting an optimal share of the network bandwidth among different traffic.

The dispatcher is executed when the medium is currently free to initiate a new communication with a slave, for the next timeslot. Thus, the dispatcher must decide, at the master side, which is the next packet to be sent, among the different available packets, and based on the different QoS requirements.

5.1 Scheduling Policy

The order of completing the traffic task is shown in Fig. 4. Every call of the dispatcher starts in the black arrow. The dashed arrow represents the promotion of periodic packets from soft to hard periodicity constraints. A Round-Robin mechanism exists between aperiodic packets of priority 0 and hard periodic packets. This allows to maintain a correct management of the network (through the hard periodic packets) for one part, and to allow critical aperiodic packets to immediately be transmitted for another part; without creating network monopolization by any of them.

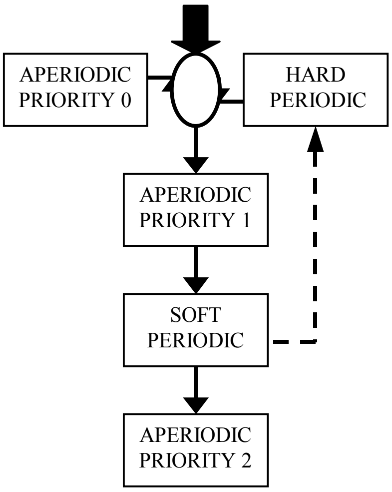

Fig. 4. Representation of the process of the different types of traffic

Afterwards the dispatcher verifies the existence of aperiodic packets of priority 1, followed by soft periodic packets and finally aperiodic packets of priority 2. This order allows aperiodic packets of priority 1 to have a higher priority than soft periodic packets, since these last have lower periodic constraints. Nevertheless, the soft periodic packet can be promoted into a hard periodic packet in order to guarantee the completion of the current activation by dual-priority dispatcher with deadline relaxation (Raul and Song, 2005).

In dual-priority policy, periodic packets possess two levels of priority: low and high level, whilst aperiodic packets are scheduled using a medium priority level. According to this, periodic packets can run immediately at a low level while there is no aperiodic traffic. With the aperiodic traffic, a soft periodic task should only be sent when promoted to the hard periodic, as late as possible.

For limitation of CPU utilization and quick reaction, it is necessary to build a simpler and faster dispatcher to avoid calculating the time instant when a low periodic packet is promoted in the every call of the dispatcher. In our system constrains, we propose that hard periodic packet is necessary to guarantee the deadline, in contract, the missing of a deadline is not problematic for the soft periodic packet. The soft periodic packet requires to follow (m,k)-firm scheduling guarantee. The idea is that for each periodic packet, its deadline as the promotion time L', that is, to have L' equal to its period T. So the dispatcher is still based on the Dual-Priority policy and respecting the most important constraint in our system: the periodicity. We call this scheduling policy as dual-priority with deadline relaxation.

Considering that several periodic packets may have the same promotion time, a periodic packet P_i should have the maximum bounded jitter of $T_i + \alpha$. The notion of promotion periods introduced, which guarantee that in at least one call of the dispatcher, every periodic packet can be successfully promoted without surpassing its deadline.

$$\alpha = \max(C_j) \qquad with\, j < i \tag{6}$$

However, it still accomplishes the needed sense of periodicity. That is, the relaxation of the deadline constraint permits the increase of the periodic packet to a maximum charge of 1. Thus, the only condition need to guarantee at every time the dispatcher is called, in following:

$$\sum_{i=1}^{M} \frac{C_i}{T_i} < 1 \tag{7}$$

where M is the number of periodic packets, C_i is the execution time of packet i, T_i is period of packet i. C_i corresponds to the number of lapsed timeslots between transmitting a packet to the slave and receiving a confirmation packet at the master. The execution time of packet i (C_i) results in the distance, in number of repeaters, needed by the downlink and uplink between master and slave, and also according to the strategy applied for adjusting the number of repeaters in the routing protocol for downlink (defined as $r_{DL}(i)$) and uplink (defined as $r_{UL}(i)$) in case of a retransmission procedure.

The execution time C_i is expressed by the following formula:

$$C_i = \sum_{k=0}^{retries\_number} \left(r_{DL}(i) + r_{UL}(i) + 2 \cdot (k+1) \right) \tag{8}$$

From section 4, we conclude that in general no retransmission is needed most of the time. A coarser calculation is possible by eliminating the retransmission:

$$C_i = r_{DL}(i) + r_{UL}(i) + 2 \tag{9}$$

5.2 Performance

The goal of the simulation is to derive transmission delay of the aperiodic packets, that is, the time between being available in the queue and sending into the PLC network. It permits to evaluate the minimization of the delay of the aperiodic packets, at the master side.

The simulation is done in a ring network with one master and nine slaves, where the master sends aperiodic packets to all slaves in a uniform manner, but always respecting the following periodic traffic:
P0 : generate one packet per every 255 timeslots, the deadline equaling to the period and has the soft periodic level
Pa : generate a polling cycle per every 3840 timeslots, the deadline equaling to the period and has the hard periodic level
Pb : generate a polling cycle per every 378 timeslots, the deadline equaling to the period and has the soft periodic level

In the scenario of a single aperiodic queue, we use a single aperiodic queue of priority 2 (normal), with a buffer size of 40 packets. In the scenario of two aperiodic queues there are Aperiodic Priority 1 and Aperiodic Priority 2 queue with each queue buffer size 20. Aperiodic packets in the first queue (Aperiodic Priority 1) have a higher priority than soft periodic packets. However, in the case of missing deadlines, these soft periodic packets are promoted to the hard periodic table, with a higher priority than any aperiodic queue, which allows not missing the deadline again.

In Fig. 5, the introduction of the promotion from soft to hard periodic level shows that with a high load (aperiodic packets generated every 5 to 8 timeslots), the aperiodic priority 2 suffers greatly, while aperiodic priority 1 still maintains a reduced delay of transmission.

In Fig. 6, we find that the same behavior in the single periodic queue scenario and the double periodic queue scenario. Thus, we can say that what influences the jitter is the load of the aperiodic queues in the system and not its priority for the deadline relaxed dispatcher approach.

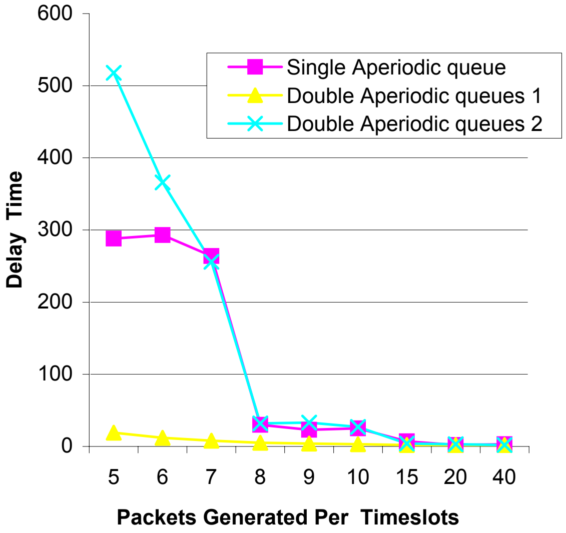

Fig. 5 Delay times of aperiodic packets generated at several timeslot units' rates

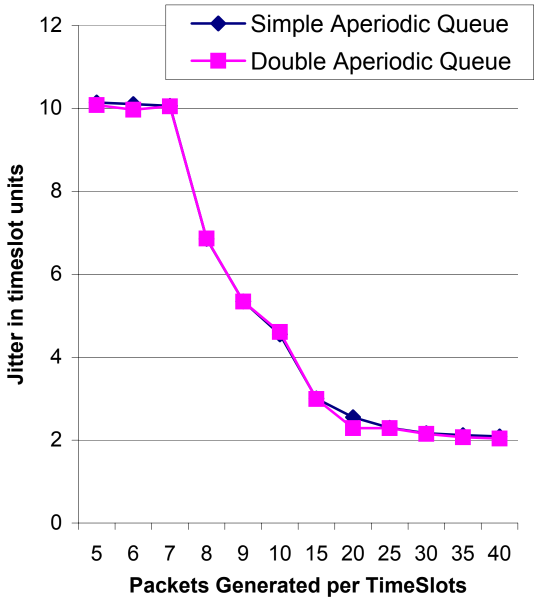

Fig. 6. Jitter of the periodic packets

6. CONCLUSION

In this paper, we propose two QoS mechanisms to satisfy the system QoS requirements. The first one is flooding-based routing protocol (SFN) which identifies a path (repeater levels) to guarantee the successful packet transfer between the master and slaves. Another one is network dispatcher of Dual-Priority scheduling policy with deadline relaxation which specifies the order of transmitting packets and supports QoS requirements. Our simulation results have shown that those QoS mechanisms guarantee minimum bandwidth utilization through periodic traffic and short end to end delay of aperiodic data request services.

REFERENCES

Draft IEEE SA technical report on substation integrated protection, control and data acquisition communication requirements (2003). Technical Report IEEETR 1525-2003, Substation Committee of the IEEE Power Engineering Society.

Markus Sebeck, Gerd Bumiller (2000). A Network Management System for Power-Line Communications and its Verification by Simulation. In: *4th International Symposium on Power-Line Communications and its applications.*

Gerd Bumiller (2002). Single Frequency Network Technology for Medium Access and Network Management. In *6th International Symposium on Power-Line Communications and its application*.

Gerd Bumiller (2004). Power-Line Physical Layer Emulator for Protocol Development. In: *8th International Symposium on Power-Line Communications and its applications*.

Gerd Bumiller, Liping Lu and Yeqiong Song (2005). Analytic performance comparison of routing protocols in master-slave PLC networks. In *9th International Symposium on Power-Line Communications and its applications*.

Raul Brito and Yeqiong Song (2005). A Dispatching Mechanism Providing REMPLI Applications with QoS. In *10th IEEE International Conference on Emerging Technologies and Factory Automation*.