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A preemptive polling protocol for applications in wireless LANs [*]

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This paper deals with a radio-based communication network with a single radio channel shared by several data terminals for transmissions to a single hub station. In particular, the communication system considered is a potential provider of wireless LAN-like services. The focus is on the capacity of combining a preemptive polling-based multiple access scheme with a Selective Repeat ARQ technique to counteract the effect of the nonstationary transmission channel. The nonstationary transmission channel has been modeled as a two-state Markov chain with parameters related to actual propagation conditions. Typical outdoor/indoor environments have been considered. The main idea is that of making the service interruption of the preemptive polling scheme dependent on the propagation conditions of the transmission channel by monitoring the outcome of the data packet transmission attempts. A performance comparison clearly reveals the superiority of this preemptive polling scheme with respect to the classical cyclic polling scheme.

1. Introduction

Wireless LANs (also referred to as WLANs) are becoming increasingly popular in response to the need for mobile computer communications. The main factor that has brought about the development of WLANs is the diffusion of an increasing number of powerful mobile computers, which in turn has lead to the need for a network architecture capable of meeting mobile users requirements. Common methods for LAN cabling inside buildings pose special difficulties. The installation step has to face problems such as the choice of the best access points and cable paths, the interruption of normal office activity, the high costs of materials and work. Moreover, the architecture of a cabled LAN does not often allow the desirable flexibility for computer location. At present, WLAN growth is reduced because of unsolved technical problems, mainly due to unsatisfactory transmitting features of the indoor radio channel (from which the term Radio LAN or RLAN) over which communications generally occur. In a typical RLAN a fixed hub station communicates via radio with terminals – fixed or mobile – indoor or outdoor, generally in urban areas [1,3]. Owing to reflection, refraction and scattering of radio waves by obstacles and building structures, the transmitted signal

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most often reaches the receiver by more than one path, leading to a phenomenon known as multipath fading. The sum of signal components arriving from different paths produces a distorted version of the transmitted signal. In narrow-band transmissions the multipath fading causes fluctuations in the received signal envelope and phase, while in wide-band transmissions the effect is to produce a series of delayed and attenuated replicas for each transmitted pulse. The received signal is further corrupted by other undesirable random effects such as noise and cochannel interference [6]. Multipath fading seriously degrades the performance of communication systems operating inside or outside buildings and represents a serious obstacle to the realization of fully reliable and efficient RLANs.

A basic component for RLAN design is the multiple access protocol to share the trasmitting medium among users. Solutions generally applied for cabled LANs cannot be used in outdoor/indoor radio environments [3] because of their harsh trasmitting characteristics. Several studies about this problem suggesting both classical access techniques, conveniently modified (capture Aloha [13], CSMA with busy tone [12,19]) and new access techniques (SDMA [21]) have been reported in literature. Random access techniques such as Aloha and CSMA are characterized by the lack of strict ordering of the users contending for access to the common channel. These protocols, also known as contention schemes, are suitable for multiplexing many bursty sources, but only when the aggregate traffic is a small portion of the system capacity. This behavior is enhanced in the case of RLANs due to the presence of multipath fading. In systems which are intended to operate with as high a load as 0.8–0.9 of their capacity, demand assignment access protocols are necessary to guarantee a stable operation and acceptable access delay values.

In demand assignment access protocol, users are required to provide explicit or implicit information regarding their needs for transmitting packets. These schemes are classified into two main groups: centralized demand assignment schemes, in which a control unit distributes the access to the common channel among the users, and distributed demand assignment schemes, in which a distributed algorithm, executed by all users, controls the channel access times. Unlike random access protocols, demand assignment schemes eliminate channel capacity wasted by collision, since collision cannot occur in these protocols. Moreover, they minimize wasted channel capacity by avoiding assignment of access to the common channel, to idle users. Distributed demand assignment schemes have the advantage of reliability, since the system operation is not dependent on a central processor. The basic need in distributed algorithms is to exchange control information among the users in order to coordinate their accessing actions. The implementation of distributed demand assignment schemes is more complex in RLANs with respect to cable LANs, in particular in the case of mobile users. Despite a lower reliability, centralized demand assignment protocols seem to be a more attractive solution than distributed demand assignment schemes for applications in RLANs. In particular they have the following advantages [3]:

- centralized control provides more reliable channel access, particularly in the case of time-varying channels;

- by assigning the most complex functions to the hub station, remote stations can be simpler and less expensive;
- centralized management enables the integration of data traffic (synchronous and asynchronous) with isochronous traffic (voice, video);
- the presence of a hub station simplifies control functions, such as network and security monitoring.

A classical centralized demand assignment protocol which, if conveniently modified, seems to be suitable for RLANs is *cyclic polling* [7,17], i.e., the coordination of channel access by a hub station polling LAN users cyclically. In particular, the focus here is on efficient cyclic polling schemes in which an Automatic Repeat reQuest (ARQ) technique [2,7,17] is used to counteract the negative effect of the harsh outdoor/indoor radio environment. It has been proved recently [5] that in outdoor/indoor radio environments the use of both cyclic polling for channel access and ARQ methods for error control leads to an unacceptable performance, due to packet transmissions occurring during bad propagation channel conditions. However, bad conditions often affect only a limited part of the RLAN coverage area, or only one terminal in motion. Under the assumption of independent channel propagation conditions for each user, this paper investigates the capacity of a cyclic polling scheme supplied by a preemption policy to avoid data transmission during bad propagation conditions.

The preemption policy is widely used in priority communication systems where we have messages with different priority levels. Transmission of messages with lower priority could be interrupted by the arrival of messages of a higher priority [16]. The novelty here devised is that of making the preemption policy dependent on the propagation conditions of the transmission channel in order to stop packet transmission when bad propagation conditions are revealed [5]. Here the identification of bad channel conditions is based on the number of consecutive packets received with errors at the hub station: a terminal accessing the common channel is inhibited to continue data transmission if N consecutive packets have been received with errors. In order to reduce the data transmission during bad channel conditions, in what follows, we have set N at 2.

The identification of the transmission channel conditions was previously considered [8,9,14] to modify the capacity of error correction in type I and type II – ARQ schemes used to control error in single user communication systems. As regards the implementation of channel release as a consequence of the preemption policy (i.e., propagation conditions of the shared channel), two alternatives have been recognized:

1. Each terminal station counts the consecutive NACKs received to identify bad channel situations. When this number reaches N, the terminal station is forced to release the access to the shared channel (before beginning a new packet transmission);
2. The hub station counts the consecutive NACKs sent to the transmitting terminal in order to identify bad channel situations. When this number reaches N, the hub

station sends out the release packet to the transmitting terminal and proceeds to poll the next terminal in the polling list.

The first method allows a distributed implementation of channel release and control of the propagation conditions of the shared channel. Conversely, the second method permits a centralized implementation (hub station) of both the operations. Owing to the advantages of centralized multi-access schemes over the distributed alternatives previously listed, we mainly focus hereafter on the second method. A brief discussion concerning implementation of the first method is given in the appendix. Performance comparisons are provided to further prove the advantages of the second approach.

2. System description and channel model

We will consider a network architecture in which a hub station (HS) controls the access of a certain number of terminal stations (TSs) – both fixed and mobile – to the radio channel. We are assuming that the motion of TS is limited to the coverage area of the HS. The transmission, slot-base synchronized, occurs over two distinct unidirectional channels: an uplink channel and a downlink channel. Data packets are transmitted over the uplink channel (from the TSs to the HS) which thereby represents the sharing channel between the different TSs. The downlink channel (from the HS to the TSs) is used for the access management to the uplink channel and for error control. It operates in a broadcast way: each transmitted packet contains the identifier of the station it is addressed to.

We are assuming that the propagation conditions of the uplink channels are independent for the individual TSs and that there is always reliable transmission for the downlink channel. This ideal condition can be met in many actual applications by taking into account that the acknowledgment packets (ARQ schemes) [2,7,17] and the polling packets are formed of few bits. Hence, the transmission of such packets can be accomplished by high power signals and/or by resorting to powerful error correcting codes in order to guarantee a very low probability of an erroneous reception for a wide range of channel propagation conditions.

Each slot allows the transmission of only one packet per channel. Its duration is assumed to be comprehensive of propagation and computation delays, assumed small with respect to packet duration. Each TS has a transmission buffer managed according to the FIFO (First In First Out) policy, where data packets wait for the first transmission attempt. After the completion of the first transmission, packets are removed from the transmitter buffer and stored in the retransmission buffer where they wait for the acknowledgment packet. The retransmission buffer is also managed according to the FIFO policy. A packet is removed from the retransmission buffer only when a positive acknowledgment (ACK) is received.

In the modeling of the radio channel, slow time-varying propagation conditions are assumed. In particular, the radio channel was modeled according to the Sinha–Gupta's channel model [18]. In this channel model, the signal level at the receiver is assumed to alternate between two states: a good state and a bad state. Let us denote by t_{good} and t_{bad} the time the channel stays in the good state and bad state, respectively. We have assumed that when the channel stays in the good state, independent bit errors occur with probability $P_{e,\text{good}}$. Conversely, in the bad state each packet is always received erroneously. Since channel state transitions may occur anywhere in time, it has been assumed that a packet is erroneously received whenever a channel state transition occurs during its transmission time.

According to the Sinha–Gupta's model, we have considered that the fading envelope is Rayleigh distributed. It follows that t_{good} and t_{bad} are random variables exponentially distributed, with probability density function defined as [18]

$$f_{t_{\text{good}}}(t) = \begin{cases} \frac{1}{T_{\text{good}}}\,\mathrm{e}^{-t/T_{\text{good}}}, & t \geqslant 0, \\ 0, & t < 0, \end{cases} \tag{1}$$

$$f_{t_{\text{bad}}}(t) = \begin{cases} \frac{1}{T_{\text{bad}}}\,\mathrm{e}^{-t/T_{\text{bad}}}, & t \geqslant 0, \\ 0, & t < 0, \end{cases} \tag{2}$$

where T_{good} and T_{bad} are the respective mean values.

The behavior of the channel model already introduced, is well described by the following parameters:

$$T_{\text{cc}} = T_{\text{good}} + T_{\text{bad}}, \tag{3}$$

$$\delta = \frac{T_{\text{bad}}}{T_{\text{good}} + T_{\text{bad}}}. \tag{4}$$

Parameter T_{cc} defined in (3) denotes the mean channel cycle time, i.e., the mean time elapsed between two consecutive good–bad (or bad–good) transitions, while parameter δ defined by (4) denotes the fading duty cycle, i.e., the ratio between the mean time in which the channel is in the bad state and the mean channel cycle time.

3. A centralized preemptive polling protocol

This section deals with the description and analysis of a preemptive polling protocol, named Hub Station Nack Preemptive (HSNP) polling protocol, in which the channel release control is implemented in a centralized manner. As for classical cyclic polling systems, both gated and exhaustive packets transmission policies have been examined [7].

A Selective Repeat ARQ error control (SR) scheme is considered to counteract transmission errors in the uplink [2,7,17]. An error detecting code able to reveal all the error patterns has been assumed [5]. The SR scheme is the most efficient ARQ scheme, where only negatively acknowledged (NACKed) packets, i.e., packets received with errors, are retransmitted. HS is assigned to reorder the original packets sequence. The assumption of a small round trip delay leads to a value for the ARQ window (the maximum number of packets awaiting acknowledgment) equal to 2. Higher window sizes may arise in the case of a wide area served by a HS or in the case of high

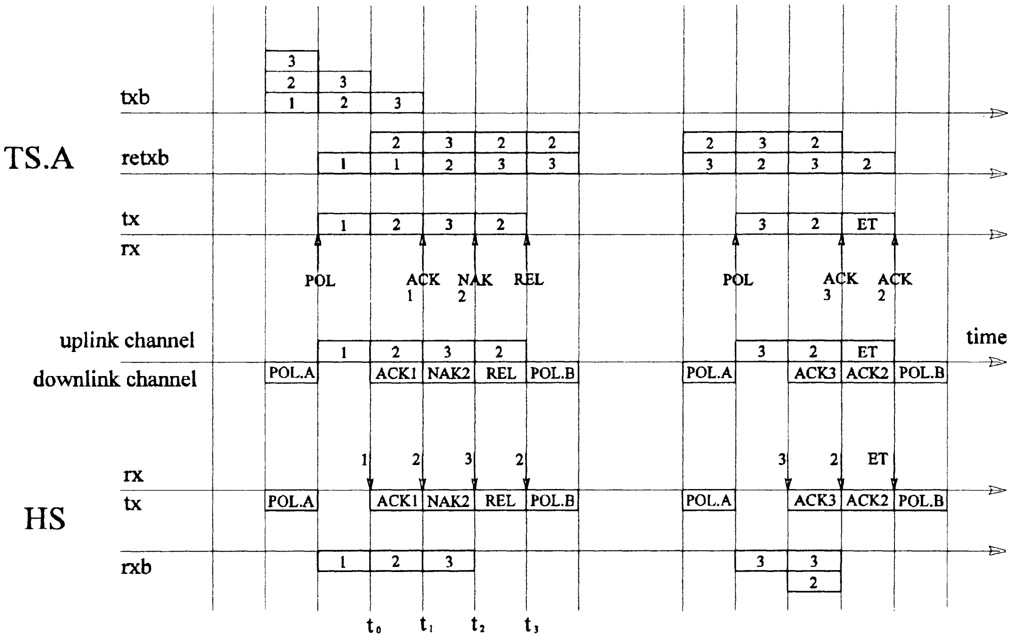

Figure 1. HSNP polling protocol: example of service interruption with $N = 2$. Data packets are numbered in their arrival order at TS; REL: channel release; POL: poll; ET: end-of-transmission. Assume that the channel enters in bad state between t_0 and t_1. Channel release happens after 3 slots (t_3).

transmission rates. In these cases, of course the performance of the proposed HSNP protocol are reduced as commonly happens for control demand assignment schemes [2,7,16,17]. However, we would like to stress that the channel release policy assumed in the HSNP polling protocol is not dependent on the window size of the SR scheme.

From the above, it follows that TSs retransmission buffer as well as packets ordering HS buffer contain at the most 2 packets simultaneously. Furthermore, according to the same assumption each ACK/NACK packet received by the TS is referred to data packet transmitted in the previous slot: thus it is not necessary that ACK/NACK packets provide a field to specify the number of packets they refer to.

Figure 1 shows an example of the operation mode in the case of transmission over a bad channel. The HS polls a TS by sending the polling packet (POL); then, the TS starts transmitting data packets. To perform the preemption function, the HS has a counter in which it tracks the number of consecutive NACKs transmitted to the TS. If the computation reaches a specified value (N), the HS sends out a channel release packet (REL) to that TS and proceeds to poll the next TS in the polling list. It can be noted that the release packet is interpreted by the TS also as a NACK for the packet transmitted in the previous slot. When the TS succeeds in transmitting all packets in its transmission buffer, it informs of this the HS by sending the end-of-transmission packet (ET).

The walk-time [2,7,17] of this polling protocol is assumed equal to 2 slots: one slot for the channel release packet (ET packet from TS or REL packet from HS) and one

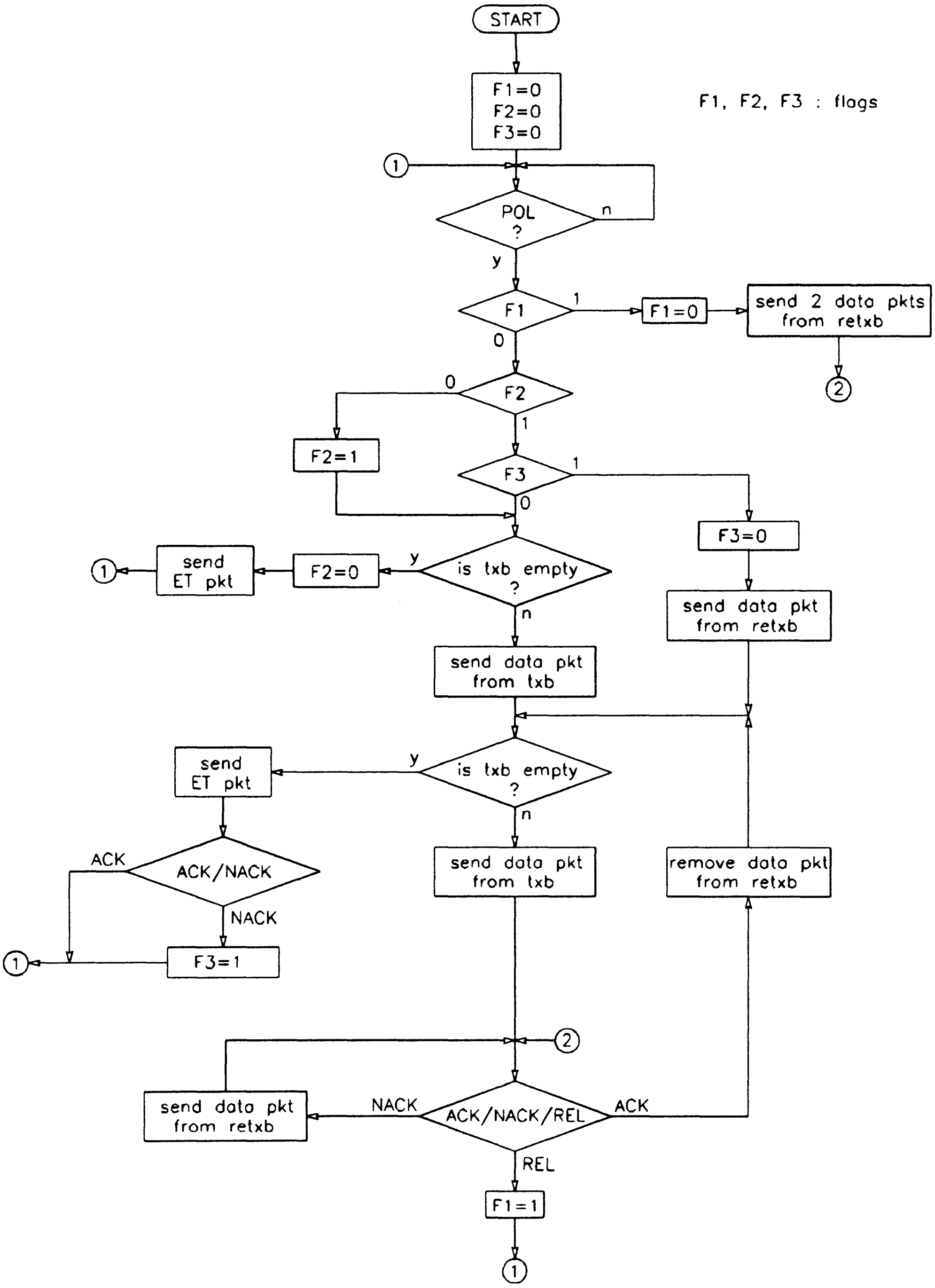

Figure 2. Implementation of the HSNP polling protocol: flow chart for TS.

slot for the polling packet (POL packet from HS). The example in figure 1 highlights that the HSNP polling protocol saves a slot at any service interruption with respect to Terminal Station Nack Preemptive (TSNP) polling protocol discussed in appendix (figure 9) in which the channel release is implemented in a distributed manner.

The flow diagram in figure 2 represents the implementation of the HSNP polling protocol for the TS. It should be noted that the TS reply to a POL packet is dependent on the state of its transmission buffer and on the values of a set of flags (F1, F2, F3) that take into account how the TS has terminated the previous service period.

By comparing figure 2 with figure 10, which shows the flow diagram concerning the implementation of the TSNP protocol at a TS, it is possible to note a reduced complexity for the HSNP protocol.

4. Performance evaluation

The performance analysis of the proposed polling scheme, in the case of a gated and exhaustive access policy, has been carried out in terms of mean packet delay time ($\overline{w}$) and mean polling cycle time (T_{cp}), i.e., the mean time required by the HS to offer access to all TSs.

We emphasize that the performance evaluation of the SR scheme in the case of time varying channels represents a very complex task. Analytical approaches proposed in the literature [4] are limited to the case of an end-to-end wireless communication. The extention of them to the case of the polling scheme proposed in this paper, even admitting it possible, appears as a very complex analytical problem to be resolved in a closed form. Hence, we have resorted here to computer simulations.

Our results have been obtained for the system parameter set given below:

number of TSs	10;
packets arrival process	Poisson;
packet length	1000 bits;
transmission bit rate	1 Mb/s;
slot time	1 ms;

number of consecutive NACKs after sending the release packet: 2;
$P_{e,\mathrm{good}} = 10^{-6}$ (i.e., packet retransmission probability $\cong 10^{-3}$);
$T_{\mathrm{cc}} = 500$ slots;
$\delta = 0.1$.

Quantities are expressed as a function of the total load ρ, defined as

$$\rho = N_{\mathrm{s}} m \lambda, \tag{5}$$

where

λ	is the mean arrival rate for each TS (packets/sec.);
N_{s}	is the number of TSs;
m	is the slot time (sec.).

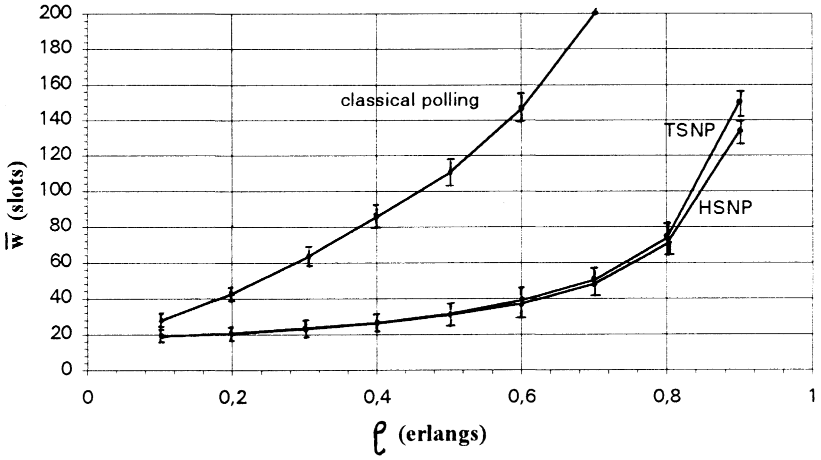

Figure 3. Mean packet delay comparison: gated policy.

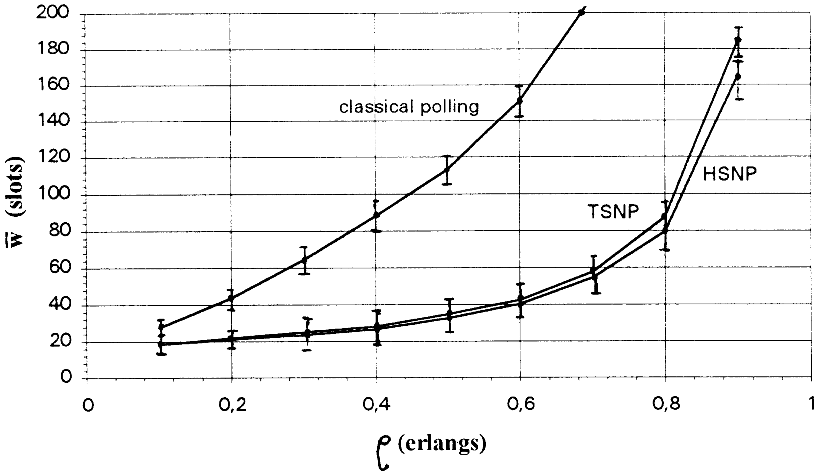

Figure 4. Mean packet delay comparison: exhaustive policy.

Since our results were obtained by means of computer simulations, we have indicated confidence intervals in the curves to quantify the reliability of our performance estimations. Several techniques have been devised for generating confidence intervals [15]. Here, we have adopted the method of independent replications. The simulation has been run ten independent times and ten estimates are thus obtained for each performance measure of interest. Each set of ten values has been used to derive the confidence interval by means of a standard statistical technique [10,20].

Figures 3 and 4 show the mean packet delay-load curves for the HSNP polling protocol, the TSNP polling protocol, and the classical cyclic polling under the gated and exhaustive service policy, respectively. These figures point out that under low values of parameter ρ, the main contribution to $\overline{w}$ is due to the walk-time. The HSNP

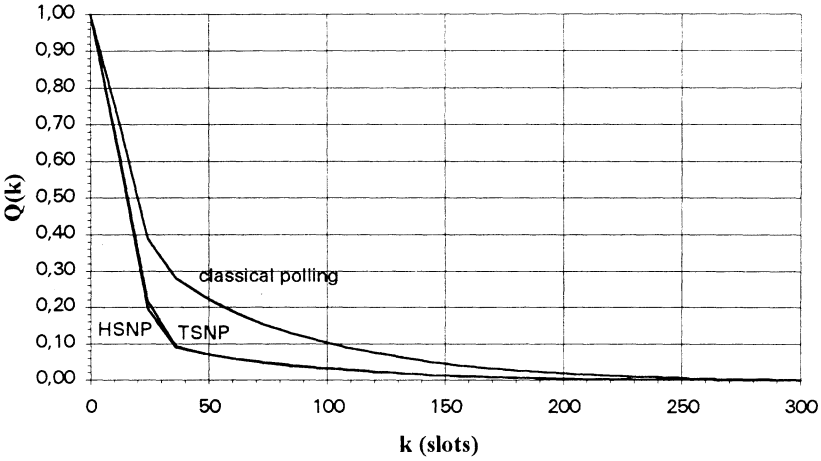

Figure 5. Probability of having a packet delay greater than k (slots): exhaustive policy, $\rho = 0.2$ (erlangs).

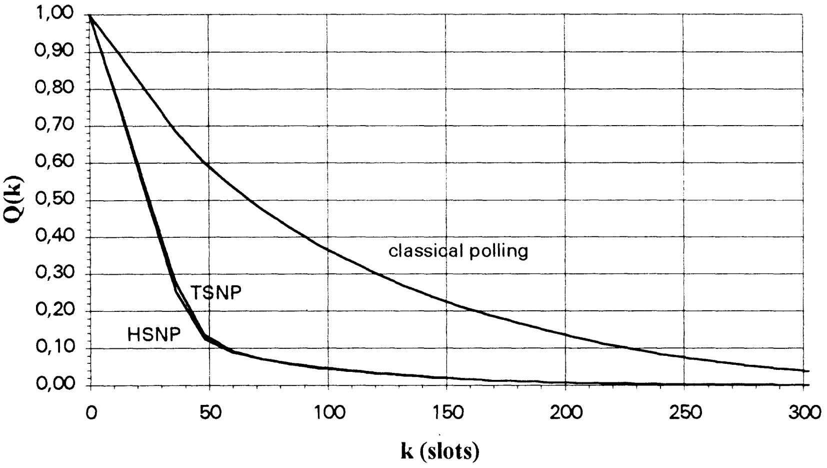

Figure 6. Probability of having a packet delay greater than k (slots): exhaustive policy, $\rho = 0.5$ (erlangs).

polling protocol is superior to the TSNP polling protocol under medium and high total traffic load conditions for both gated and exhaustive policy. This is mainly due to the saving of one slot in the HSNP case every time a TS suffers a service interruption (figures 1 and 9).

The comparison between the classical cyclic polling protocol (combined with the SR scheme) and the preemptive polling protocols highlights the significant performance improvement allowed by the service interruption method (HSNP and TSNP protocols).

The maximum possible value of ρ for both the TSNP and HSNP protocols is equal to 0.94 (erlangs) while for a classical cyclic polling scheme it is 0.82 (erlangs).

A more deeper analysis of the performance of the HSNP polling protocol has been obtained by the estimation of the packet delay time probability distribution.

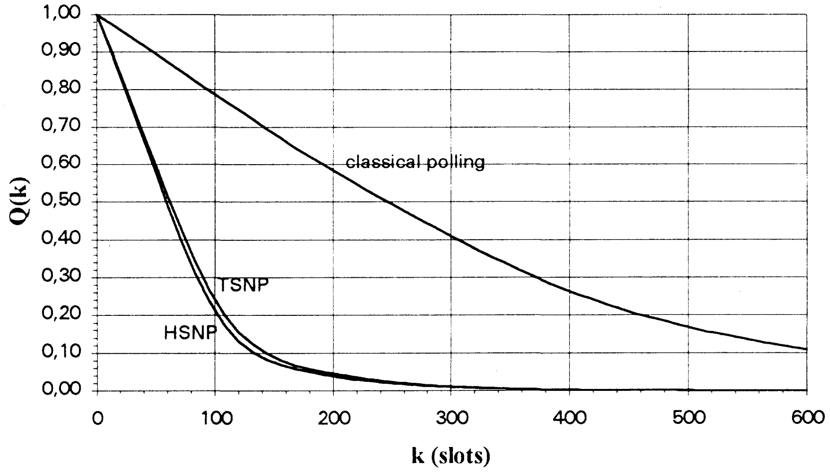

Figure 7. Probability of having a packet delay greater than k (slots): exhaustive policy, $\rho = 0.8$ (erlangs).

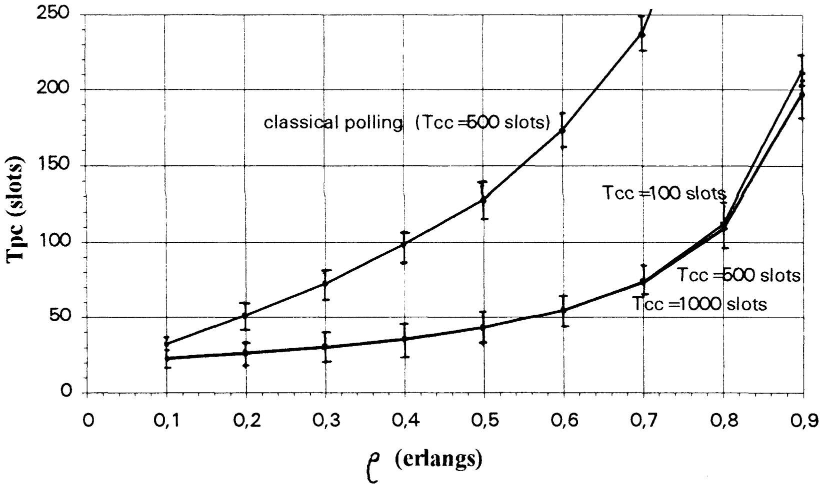

Figure 8. Mean polling cycle time comparison.

Figures 5–7 show $Q(k)$, i.e., the probability that the packet delay (w) is greater than or equal to k (slots), for the proposed HSNP polling protocol, TSNP and classical cyclic polling protocol combined with the SR scheme. These figures show once again that the HSNP and TSNP polling protocol outperforms the classical scheme, with the HSNP polling protocol exhibiting the lowest $Q(k)$ for any value k of the packet delay.

Another important parameter to be evaluated is the mean polling cycle time (T_{cp}). Generally, in polling systems cycle time increases when load increases, since the channel holding time for each station increases. In a preemptive polling scheme, the service period can be interrupted by the occurrence of bad propagation conditions

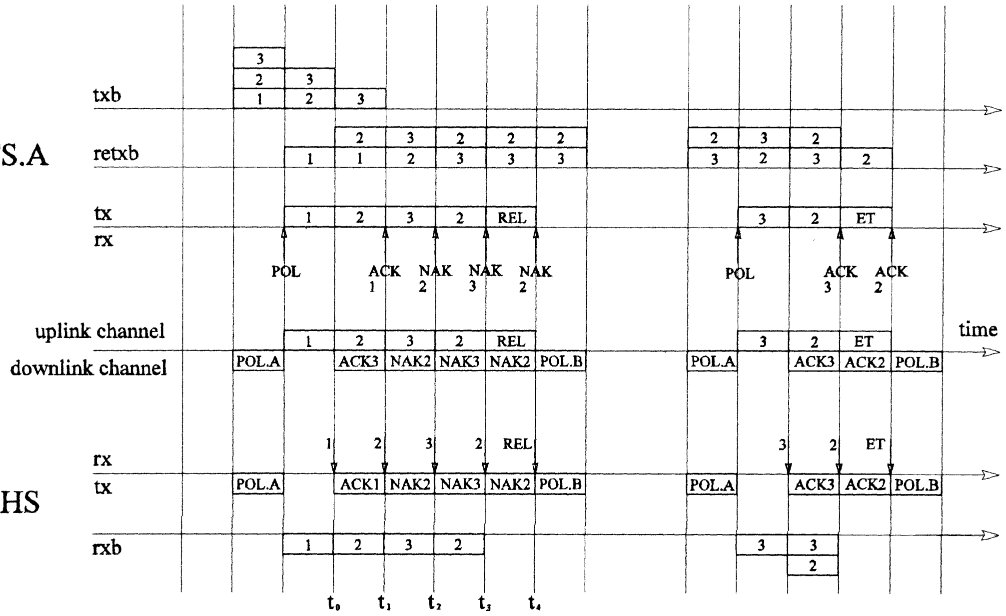

Figure 9. TSNP polling protocol: example of service interruption with $N = 2$. Data packets are numbered in order of their arrival at TS; REL: channel release; Pol: poll; ET: end-of-transmission. Assume that the channel enters in bad state between t_0 and t_1. Channel release happens after 4 slots (t_4).

for the transmission channel. Therefore, in RLANs the preemption technique reduces the polling cycle time with respect to the classical cyclic polling scheme.

Figure 8 shows parameter T_{cp} as a function of ρ for three different values of T_{cc} for the HSNP polling protocol and classical cyclic polling protocol, in the case of the exhaustive transmission policy. This figure points out that the preemption policy assumed for the HSNP protocol makes parameter T_{cp} independent of T_{cc} for a wide range of values. It should be noted that when load decreases, the mean cycle time is close to the value of 20 slots, in accordance with the assumed walk-time value (2 slots) and TSs number (10 stations). This figure also highlights the significant reduction of T_{cp} for the HSNP polling protocol with respect to the classical cyclic polling protocol.

5. Conclusions

In this paper, an efficient preemptive polling multiple access scheme was proposed to provide spatially dispersed terminal stations with a radio access to a hub station over a common short-range radio channel. This scheme was combined with the SR technique to enhance the data transmission reliability and to make the service interruption dependent on the propagation conditions of the transmission channel. A performance evaluation of the proposed preemptive polling access scheme was carried out under particular assumptions. The results presented in the paper provide some useful information even if it is evident that much more needs to be done to completely

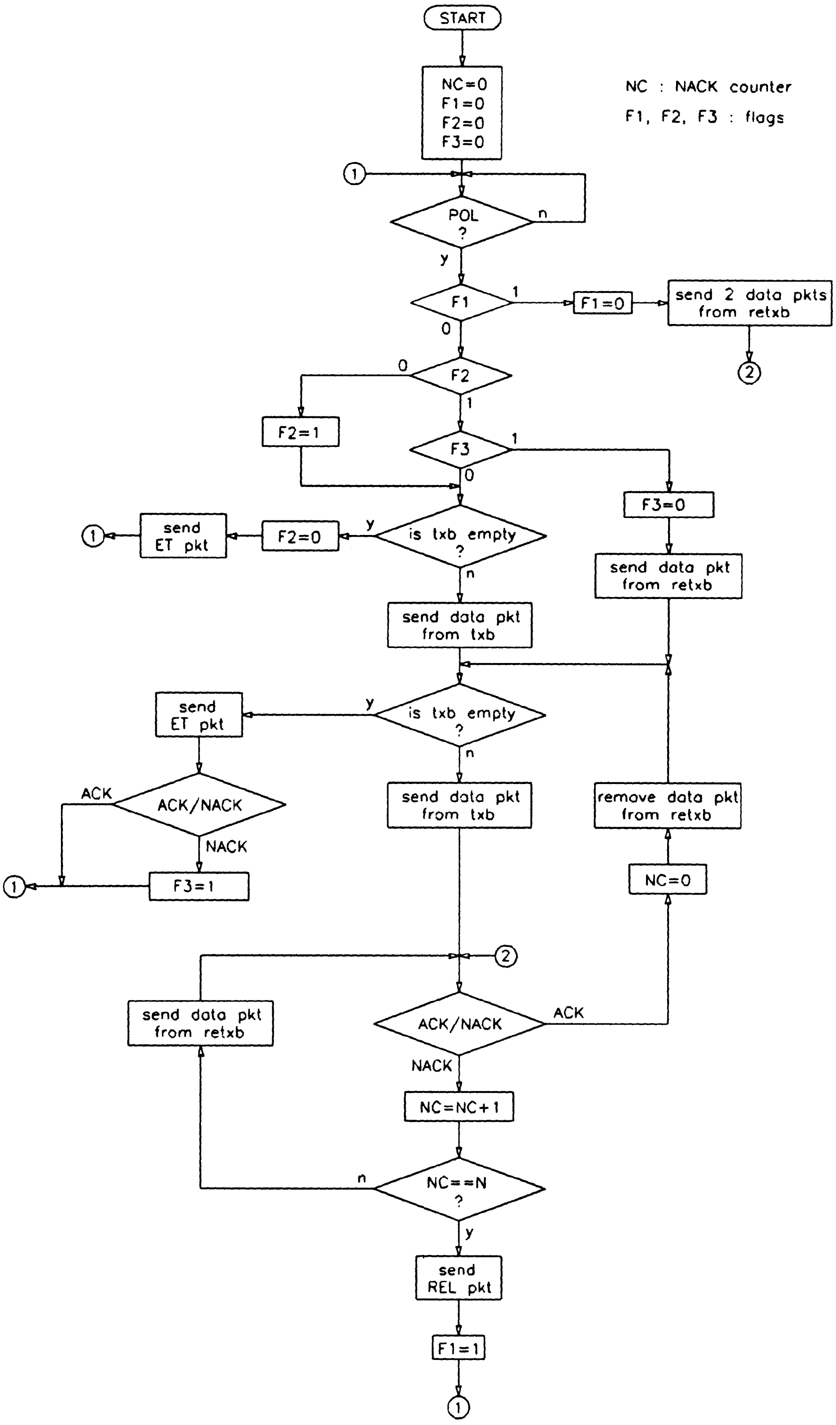

Figure 10. Implementation of the TSNP polling protocol: flow chart for a TS.

address practical scenarios. In particular, this paper clearly shows the effectiveness of the use of the SR technique in a preemptive polling multiple access scheme to counteract burst errors introduced by the nonstationary transmission channel. In comparison with the classical cyclic polling scheme, this preemptive polling scheme proves to be more efficient.

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Appendix

This appendix deals with the proposal of an alternative preemptive polling protocol, named Terminal Station Nack Preemptive (TSNP) polling protocol in which the channel release is implemented in a distributed manner. Figure 9 shows an example of the operation mode in the case of transmissions during bad channel propagation conditions. The flow diagram relative to a TS is sketched in figure 10. Also in this case, both gated and exhaustive policies have been considered in ordering the transmission of packets buffered at each TS.

The TSNP polling protocol differs from the HSNP polling protocol, discussed in section 3, only in the implementation of the preemption function, managed by TSs. Each TS has a counter (NC), to count the number of consecutive NACKs received during the time the TS is accessing the shared uplink channel. If the computation reaches a specified value (N), the TS is forced to send out the ET packet even if packets transmission has not been completed.

The walk-time for the TSNP polling protocol is equal to 2 slots: one slot for the ET packet sent by the TS and one slot for the POL packet sent by the HS.

The performance of the TSNP polling protocol is shown in figures 3–8 of the text, in terms of mean packet delay (figures 3 and 4), $D(k)$ (figures 5–7), and T_{cp} (figure 8).

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