PDSMA: Pseudo-Deterministic Statistical Multiple Access for Voice Packets Uplink Scheduling

Marwen Abdennebi and Samir Tohmé

PRiSM Laboratory, CNRS - UMR 8144
University of Versailles - France
firstname.lastname@prism.uvsq.fr

Abstract – Statistical multiple access gives opportunity to decrease bandwidth wastes in radio cellular networks when sources activities are variable. Usually, 2 states exponential ON-OFF models are used for voice sources and to study statistical multiplexing in telephony. In this paper, we propose a distributed algorithm based on a 3-states model with downlink activity detection for a refined prediction. The proposed algorithm makes the distinction between silent sources according to their downlink activities to enhance the statistical multiple access for telephony. Then, silent sources are pre-allocated available channels on the uplink according to their respective switching probabilities; hence the designation “pseudo-deterministic” for our proposed statistical multiple access scheme. Performance evaluation (analytical and simulation model) is given to illustrate the benefits of our proposal.

I. INTRODUCTION

Radio cellular telecom networks are usually based on fixed multiple access schemes like TDMA (Time Division Multiple Access), FDMA (Frequency Division multiple Access), CDMA (Code Division multiple Access) or recently OFDMA (Orthogonal Frequency Division multiple Access). Those access schemes are especially suitable for telephonic applications as voice packets access delay and jitter should be guaranteed for acceptable quality of service.

However, voice sources characterising shows active and silent periods that could be used for bandwidth utilisation gain. Statistical multiplexing exploits statistical behaviour of traffic and especially voice sources to decrease bandwidth allocated for the same capacity in term of accepted calls. Usually, with voice activity detection, silent sources are not allocated channels and must randomly access unused channels when switching to active mode. To obtain bandwidth gain, the mean number of free channels is mostly less than the number of silent source; a 2-states model (ON-OFF) is used to model the aggregate traffic.

PRMA [1] is one of the most known protocols for voice packet uplink control. It is an extension of slotted ALOHA systems [2] and R-ALOHA [3]. PRMA uses a pseudo-random access scheme when silent sources become actives taking advantage of the loss tolerance of voice as a 1% loss rate does not affect perceived quality [1] [4].

In this paper, we propose to enhance statistical multiple access for voice packets scheduling in the uplink. The proposed algorithm is distributed and aims to decrease collision rate. It results in Quality of Service (QoS) enhancement for users and an increased capacity.

Unlike existing uplink access schemes which use models with 2 states for voice activity, active and silent [5] [6], the model we used splits the silent state, or OFF mode, into two sub-states according to the conversation partner activity. Hence, it is possible to detect silence states where the source is listening, this using downlink activity that corresponds to listening state. Below, figure 1 illustrates the difference between short pauses that are most likely to correspond to downlink silence and long pauses that are more likely to correspond to a downlink activity.

This paper is organised as follows. In section II we describe our proposed pseudo-deterministic access distributed algorithm. Then, we model the whole system and we compute the loss probability in the cell (a simulation model confirmed the analytical results). In section IV, the performance evaluation illustrates the interest of our proposed statistical multiple access scheme. Finally, we end with our concluding remarks in the last section.

II. PDSMA: PROPOSED ALGORITHM DESCRIPTION

The proposed pseudo-deterministic distributed algorithm handles multiple access scheduling on the uplink in a cellular context. It is based on the statistical behaviour of voice activity correlated to downlink activity. Our proposal consists in taking advantage of the lowest transition probability of voice sources in long speaking silence to handle the statistical pre-allocation.

As illustrated by figure 1, silent periods could be distinguished between long pauses while listening and short pauses while speaking. Each silent source is assigned by the distributed algorithm (implemented in each client) an available channel to be used when switching to active mode. If the considered channel status changes while source still inactive, another available channel should be assigned. The base station should update its beacon to indicate to the algorithm each channel status.
In this purpose, we split silent mode into 2 states for according to downlink activity, which is the voice activity of correspondent. Basing on uplink and downlink activities, it is possible to predict user state and grant resources in a more appropriate manner.

To decrease the collision probability, available channels to be used by each idle source when releasing are assigned in advance. In this case, a collision occurs when two or more idle sources assigned to the same available channel awake in the same time interval. We considered fixed sizes voice packets like those generated by AMR codec [7] for example, meaning one fixed channel per frame and per active source (one channel for one voice packet).

If \( N_{is} \) is the number of sources in idle mode and \( N_{ac} \) the number of available slots, we will generally have more than one assigned source for each available channel. Among those \( N_{is} \) sources, \( i \) sources have an idle downlink (UL/DL = OFF/OFF) and \( j \) ones have an active downlink (UL/DL = OFF/ON). We suppose that the BS broadcasts in its beacon the sources states according to their IDs in a simple \( 2xN_{is} \) (UL and DL) binary vector. This added beacon consists almost in one added channel. The beacon should be updated each frame period in case of a modification.

Silent sources are classified according to their IDs and are assigned to an available channel (also classified), one by one, in a round robin manner. To minimise collision probability, we minimise the number of OFF/OFF sources pre-assigned in the same available channel. Of course, the number of idle sources pre-allocated to the same channel is necessary greater than one.

2 sources states are defined according to UL status: active UL state and inactive UL state which could itself be divided according to DL activity. There are also two kinds of channels: active channels occupied by active sources, and non-active, or available channels, which are available for idle sources (non-active on the UL).

Below, an example of \( N_{ac} \) channels reserved (used by active sources) and \( N_{ac} \) available channels assigned for idle sources. The total number of channels is \( N_c \). Note that channels division could be TDMA based or FDMA (or even OFDMA). We call channel each resource unity and our model could be applied to each kind of multiple access.

We minimise the number of OFF/OFF sources pre-assigned to the same available channel. Of course, the number of idle sources pre-allocated to the same channel is necessary greater than one.

\[ N_{is} \] silent sources access one assigned source for each available channel. Among those \( N_{is} \) sources, \( i \) sources have an idle downlink (UL/DL = OFF/OFF) and \( j \) ones have an active downlink (UL/DL = OFF/ON). We suppose that the BS broadcasts in its beacon the sources states according to their IDs in a simple 2x\( N_{is} \) (UL and DL) binary vector. This added beacon consists almost in one added channel. The beacon should be updated each frame period in case of a modification.

Silent sources are classified according to their IDs and are assigned to an available channel (also classified), one by one, in a round robin manner. To minimise collision probability, we minimise the number of OFF/OFF sources pre-assigned in the same available channel. Of course, the number of idle sources pre-allocated to the same channel is necessary greater than one.

2 sources states are defined according to UL status: active UL state and inactive UL state which could itself be divided according to DL activity. There are also two kinds of channels: active channels occupied by active sources, and non-active, or available channels, which are available for idle sources (non-active on the UL).

Below, an example of \( N_{rc} \) channels reserved (used by active sources) and \( N_{ac} \) available channels assigned for idle sources. The total number of channels is \( N_c \). Note that channels division could be TDMA based or FDMA (or even OFDMA). We call channel each resource unity and our model could be applied to each kind of multiple access.

\[ N_{rc} \] reserved channels (occupied)
\[ N_{ac} \] available channels
\[ N_{total} \] total channels

Fig. 2. Pre-allocation scheme (distributed) for \( i+j \) silent sources access

If collided, concerned sources should then shift their pre-assigned available channels to other ones before re-attempting to transmit. Shift vector depends on relative classification numbers \( k \) or \( l \) (given from the ID) to avoid having the same pre-allocation (concerned IDs are known thanks to the precedent pre-assignment). When re-attempting in the next frame, it is possible to re-send the collided packet (meaning an added delay) to decrease losses, or to drop it (i.e., no added delay) and send the next packet of the talk spurt. To simplify the analysis we suppose that the re-attempt should occur in the next frame; however, the proposed pre-allocation algorithm could also be applied on other re-transmission schemes for collided packets.

If no collision occurs, the slot will be reserved exclusively for this source during all its active period. Beacon is then updated and the other idle sources will be re-assigned to other available channels. Proposed algorithm is presented below, with \( c \) the number of collided sources in the precedent frame and in each concerned channel.

\[ \text{// Idle sources pre-allocation} \]
\[ \text{If } N_{ac} > N_{ac} + c \]
\[ i = \text{sort}(i) \text{ sorting according to the } i \text{ IDs} \]
\[ j = \text{sort}(j) \text{ sorting according to the } j \text{ IDs} \]
\[ \text{For } k \text{ from } 1 \text{ to } l' \text{ do} \]
\[ \text{Assign Channel}(k) \text{ modulo } N_{ac} \text{ to Source}(k) \]
\[ \text{End-for} \]
\[ \text{For } l \text{ from } 1 \text{ to } j' \text{ do} \]
\[ \text{Assign Channel}(l) \text{ modulo } N_{ac} \text{ to Source}(l) \]
\[ \text{End-for} \]
\[ \text{End-if} \]

\[ \text{// Collided sources pre-allocation (consecutive to the 1st one)} \]
\[ \text{If } N_{ac} > N_{ac} + c \]
\[ c = \text{sort}(c) \text{ sorting according to the } c \text{ IDs} \]
\[ \text{For } n \text{ from } 1 \text{ to } c' \text{ do} \]
\[ \text{Assign Channel}(n) \text{ modulo } N_{ac} \text{ to Source}(n) \]
\[ \text{End-for} \]
\[ \text{End-if} \]

III. SYSTEM MODELLING AND DESCRIPTION

The original 6 states Brady model [5] describes voice activity for each partner of the telephonic conversation. Another study [8] confirmed the importance of interactivity on Voice over IP (VoIP) models. The 8-states model proposed in [9] gives an extension of Brady model with smaller silence detection. This model is especially suited for accurate voice analysis rather than for resource allocation. Another model [10] proposes an accurate hyper-exponential model which gives three different OFF states/durations but with no direct correlation between those different OFF states and the partner activity. We then have chosen to use the original well known 6-states Brady model (figure below) to assess the 3 states model needed for the pre-allocation proposed scheme.

Fig. 3. The 6-states Brady model [5] [9]
States probabilities are given from balance equations:
\[\pi(1)\alpha_{a,a} + \pi(3)\alpha_{a,b} + \pi(5)\alpha_{a,s} = \pi(4)\alpha_{a,1} + \pi(3)\alpha_{a,3}\]
\[\pi(2)\alpha_{a,2} + \pi(5)\alpha_{a,s} = \pi(1)\alpha_{a,1} + \pi(3)\alpha_{a,3} + \pi(6)\alpha_{a,6}\]
\[\pi(4)\alpha_{a,1} + \pi(5)\alpha_{a,s} = \pi(1)\alpha_{a,1} + \pi(6)\alpha_{a,6}\]
\[\pi(6)\alpha_{a,5} + \pi(3)\alpha_{a,5} + \pi(4)\alpha_{a,5} + \pi(5)\alpha_{a,6} = \pi(2)\alpha_{a,2} + \pi(5)\alpha_{a,s} + \pi(6)\alpha_{a,6}\]

Conservation equation should also be added:
\[\sum_{i=0}^{N} \pi(i) = \pi(1) + \pi(2) + \pi(3) + \pi(4) + \pi(5) + \pi(6) = 1\]

For our proposed distributed algorithm, a 3-states model is defined:
- State (1): source active on the UL
- State (2): source inactive on the UL with activity detected on the DL
- State (3): source inactive on the UL and on the DL

States durations are considered exponentially distributed, hence the associated Markov chain below:

![Markov Chain Diagram](image)

The following 2 dimensions Markov chain (figure 5) describes the probability distribution of \((i,j)\) states, i.e., inactive sources. It gives the probability of each \(i\) OFF/OFF and \(j\) OFF/ON states. Unlike usual models, transitions occur according to voices activities of the two partners of the telephonic conversation.

![State Transitions Diagram](image)

For balance states equations to determine the expressions of \(\pi_{ij}\) probabilities of the chain states \((i,j)\) as follows:

**For \(i = j = 0\), all sources are active on the UL (drops)**
\[\pi_{0,0,N}(i,j)\alpha_{1,i,j} N\gamma_{1} + N\gamma_{2} = \pi_{1,0\gamma_{3} + \pi_{0,1\gamma_{2}}}
\]

**For \(1 \leq i < N, j = 0\), no OFF/ON sources**
\[\pi_{i,0\gamma_{3} + j}(i,j)\alpha_{1,i,j} (N-i)\gamma_{1} + j\gamma_{2} + \gamma_{3} = (i+1)\pi_{i,0\gamma_{3} + j} + j\alpha_{1,0\gamma_{3} + j} + (N-i)\gamma_{1} + \gamma_{2} + \gamma_{3}
\]

**For \(i = N, j = 0\), all sources are silent on the UL and the DL**
\[\pi_{N,0\gamma_{3} + j}(i,j)\alpha_{1,i,j} N\gamma_{1} + N\gamma_{2} = \pi_{N,1\gamma_{3} + N\gamma_{2}} = \pi_{N,1\gamma_{3} + N\gamma_{2}}
\]

**For \(i = 0, 1 \leq j < N\), no OFF/ON sources**
\[\pi_{0,j\gamma_{3} + i}(i,j)\alpha_{1,i,j} (N-j)\gamma_{1} + j\gamma_{2} + \gamma_{3} = (N-j)\pi_{0,j\gamma_{3} + i} + j\alpha_{1,j\gamma_{3} + i}
\]

**For \(i = 0, j = N\), all are silent on the UL with an active DL**
\[\pi_{0,N\gamma_{3} + j}(i,j)\alpha_{1,i,j} N\gamma_{1} + N\gamma_{2} = \pi_{N,1\gamma_{3} + N\gamma_{2}} + \pi_{N,0,1\gamma_{3} + N\gamma_{2}}
\]

**For states \(i + j = N\), all sources are silent on the UL; corresponds to the diagonal of the 2-dimension Markov chain**
\[\pi_{N,i\gamma_{3} + j}(i,j)\alpha_{1,i,j} (N-i)\gamma_{1} + j\gamma_{2} + \gamma_{3} = (i+1)\pi_{i+1,N-i\gamma_{3} + j} + j\alpha_{1,i+1,N-i\gamma_{3} + j}
\]

We also add probability conservation equation:
\[\sum_{i=0}^{N} \sum_{j=0}^{N} \pi_{ij} = 1\]
Those equations were solved numerically using MATLAB [11]. Figure below illustrates the probability distribution of silent sources according to downlink activity for an example of \( N = 50 \) voice sources/telephonic calls.

Drop/collision Probability Calculation
Collision occurs when an idle source (in OFF/OFF or OFF/ON modes) switches to active mode and collides with another one in the same pre-assigned channel. Thus, as we consider a framed scheme, these sources should switch to active mode in the same frame interval \( \tau \). Note that we consider in this section that collided and dropped packets are considered lost which corresponds to pessimistic condition for loss rate.

The switching probabilities of idle sources are defined: \( P_{ri} \) for those with downlink inactive and \( P_{rj} \) for those with downlink active. These probabilities depend on the DL activity state, hence, using memory less property we obtain:

\[
P_{ri} = P(t_{OFF/ON} \leq \tau) = \int_0^\tau \gamma_{21} \exp(-\gamma_{21} + \gamma_{23}) \tau d\tau
\]

\[
P_{rj} = \frac{\gamma_{21}}{\gamma_{21} + \gamma_{23}} (1 - \exp(-(\gamma_{21} + \gamma_{23}) \tau))
\]

\[
P_{ai} = P(t_{OFF/OFF} \leq \tau) = \int_0^\tau \gamma_{21} \exp(-\gamma_{21} + \gamma_{23}) \exp(-\gamma_{21} + \gamma_{23}) \tau d\tau
\]

\[
P_{ai} = \frac{\gamma_{21}}{\gamma_{21} + \gamma_{23}} (1 - \exp(-(\gamma_{21} + \gamma_{23}) \tau))
\]

We call \( P_x \) the probability of that an active source switches to OFF (on the uplink).

\[
P_x = P(t_{ON} \leq \tau) = \int_0^\tau \mu \exp(-\mu \tau) d\tau = 1 - \exp(-\mu \tau)
\]

\( \mu = \gamma_{12} + \gamma_{13} \)

For the usual 2 states ON-OFF model, we find the well known switching probability \( P_f \):

\[
P_f = P(t_{OFF} \leq \tau) = 1 - \exp(-\lambda \tau); \quad \lambda = \frac{\gamma_{21} P(2) + \gamma_{23} P(3)}{P(2) + P(3)}
\]

We can express \( N_{off} \) the mean number of frames elapsed during the OFF period.

\[
E[N_{off}] = \sum_{k=1}^N k P_x (1 - P_x) = \frac{T_{off}}{\tau}
\]

The mean number of packet sent in talk spurt, \( N_{on} \), is:

\[
E[N_{on}] = \sum_{k=1}^{N_{off}} k P_x (1 - P_x) = \frac{T_{off}}{\tau}
\]

We can compute the number of available channels \( N_{ac} \) according to \( N_{on} \), \( (i+j) \) and the total number of channel \( N_c \).

\[
N_{ac} = \begin{cases} \frac{N_c - N - i - j}{N_{off}} & \text{if } i + j > N - N_{ac} \\ 0 & \text{if } i + j > N - N_{ac} \end{cases}
\]

Then we compute the channel allocation load, \( CL \), which is the number of idle sources that have been pre-assigned to each available channel, i.e., might contend to each available channel. The value of \( CL \) could take two different values, \( CL_1 \) and \( CL_2 \), as it could vary between available channels. Moreover, we should distinguish channel load \( CL \) according to the number of OFF/OFF and OFF/ON sources assigned to each channel. Let \( CL_i \) the number of OFF/OFF sources assigned and \( CL_j \) the number of OFF/ON assigned sources:

\[
CL_1 = \begin{cases} 0 & \text{if } i + j > N - N_{ac} \\ \frac{N_c - N - i - j}{N_{off}} & \text{if } i + j > N - N_{ac} \end{cases}; \quad CL_2 = \begin{cases} 0 & \text{if } i + j > N - N_{ac} \\ \frac{N_c - N - i - j}{N_{off}} & \text{if } i + j > N - N_{ac} \end{cases}
\]

Thus, we will have a homogenous distribution of channels allocation load, which could differ only by one OFF/OFF and/or one OFF/ON assigned source.

We can compute the number of available channels with a load of \( CL_1 \) and \( CL_2 \), respectively \( N_{ac1} \) and \( N_{ac2} \), thus for each \( i \) and \( j \) states.

The number of available channels pre-assigned for OFF/OFF sources becomes:

\[
N_{ac1} = \frac{N_{ac} - i - N_{ac}}{N_{ac1}}; \quad N_{ac2} = \frac{i}{N_{ac1}}
\]

The number of available channels pre-assigned for OFF/ON sources becomes:

\[
N_{ac1} = \frac{N_{ac} - j + N_{ac}}{N_{ac1}}; \quad N_{ac2} = \frac{j}{N_{ac1}}
\]

\[
N_{ac} = \max(N_{ac1}, N_{ac2}, N_{ac1} + N_{ac2})
\]

Then, if an idle source becomes active, it will contend only for its assigned channel with a maximum of \( CL_2 \) other idle sources.

We define drop/collision probability \( P_{drop/coll} \) as the probability that each packet of the talk spurt has to be dropped or to collide with another one.

First, we compute \( P_{coll} \), the probability of collision of the first voice packet of a source that just becomes active.

This probability depends on the state \( \pi_{ij} \) and on \( P_{coll}(N_{ac}, N_{is}) \), the collision probability when being in this state \((i,j)\) with \( N_{ac} \) available channels and \((i'j')\) idle sources.

\[
P_{coll} = \sum_{i=1}^N \sum_{j=1}^N \pi_{ij} P_{coll}(N_{ac}, i + j > 1)
\]

First, we consider the case where at least one free channel is available \((N_{ac} \geq 1)\). It means that the number of active sources \((N-i-j)\) is less that the total number of channels, \( N_c \).

Using \( P_{ri} \) and \( P_{rj} \), equations (1) (2), we can compute the collision probability in each available channel. The collision
This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the ICC 2008 proceedings.

...probability is the probability to have at least one other idle source that releases in the same frame interval of the considered source. We compute $P_{coll/i}$ and $P_{coll/j}$ respectively the collision probability for an OFF/OFF source (from $i$ ones) and for an OFF/ON source (from $j$).

$$P_{coll/i}(Nac \geq 1; i) = 1 - (1 - P_{\lambda})^{CL_{0}}(1 - P_{\mu})^{CL_{0}}$$

$$P_{coll/j}(Nac \geq 1; j) = 1 - (1 - P_{\lambda})^{CL_{0}}(1 - P_{\mu})^{CL_{0}}$$

Therefore, we can compute the collision probability related to the whole Nac available channels:

$$P_{coll}(Nac \geq 1; Nis) = \frac{1}{Nac} \cdot (Nac \cdot P_{coll/i} + Nac \cdot P_{coll/j})$$

No available channels means that all channels are reserved for active sources. Therefore, if the number of active sources exceeds the total number of channels $Nc$, a silent source that has just switched to ON will be dropped.

$$P_{drop}(Nac = 0; i, j) = 1$$

Hence, we deduce the probability of collision for the first packet sent and for the whole states represented by the 2-D Markov chain.

$$P_{coll} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \pi_{i,j} \cdot P_{coll/i,j}(Nac \geq 1; i, j)$$

$$P_{coll/i,j}(Nac \geq 1; i, j) = \frac{1}{1+j} \cdot (P_{coll/i} + j \cdot P_{coll/j})$$

We also express the drop probability assuming that a drop occurs when no available channel remains, $Nac = 0$.

$$P_{drop} = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \pi_{i,j} \cdot P_{drop}(Nac = 0; i, j)$$

As we have $P(Nac=0; i, j) = 1$ when $N-i+j \geq Nc$, we can also express drop probability using parameters $\lambda$ and $\mu$ of the 2-states model given from the classical 1 dimension Markov chain.

$$\sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \pi_{i,j} \cdot P_{drop}(Nac = 0; i, j) = \sum_{i=0}^{N-Nc} \sum_{j=0}^{N-Nc} \pi_{i,j} = \sum_{k=0}^{N-Nc} \pi_{k}$$

With: $\pi_{k} = \frac{N}{k+1} \cdot \frac{\rho^{k}}{(1+\rho)^{N}}$; $\rho = \frac{\lambda}{\mu}$; $k = N - i - j$

Then, we express the collision probability $P_{drop/coll}$ using results obtained in $P_{coll}$ expression. This probability should be extended to all packets of a talk spurt and must be computed for each $m^{th}$ packet of the talk spurt.

$$P_{drop/coll} = E[P_{coll} + P_{drop}] = \sum_{m=1}^{\infty} P(m) \cdot P_{coll/coll}(m)$$

We then use equation (3) in a way comparable to equations (4) and (5):

$$P_{drop/coll} = \sum_{m=1}^{\infty} P(m) \cdot (1 - P_{\mu})^{m-1} \cdot \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=0}^{N} \pi_{i,j,k}(Nac \geq 1; i, j, k)$$

$$P_{drop/coll} = \sum_{m=1}^{\infty} P(m) \cdot (1 - P_{\mu})^{m-1} \cdot \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=0}^{N} \pi_{i,j,k}(Nac \geq 1; i, j, k)$$

This last equation will be used in performance analysis section to compare PDSMA enhancement to pseudo-random access schemes. Obtained collision probabilities in those kinds of schemes are as follows (example for $i$ sources):

$$P_{coll/i} = \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=0}^{N} \left( \begin{array}{c} i+j \end{array} \right) P_{\lambda}^{i-1}(1 - P_{\mu})^{j-1} \cdot \pi_{i,j,k}(Nac \geq 1; i, j, k)$$

in pseudo-random schemes

Note that we considered that re-transmission after collision occurs in the next frame with an equivalent PRMA permission probability $p = 1/Nac$ with one attempt per frame.

**IV. PERFORMANCE EVALUATION**

In this part we evaluate enhancement obtained through PDSMA scheduling algorithm comparing it to a classical pseudo-random access scheme. Evaluation was done for various numbers of sources $N$ and various capacities (channel number $Nc$ including the increased beacon size in PDSMA). The frame period $\tau$ is fixed to 20 ms and $\omega_{ns}$ values\(^1\) were taken from the well known Brady measurements [5]. A simulation model of the pre-allocation algorithm (implemented in C++) with a framed scheme confirmed the analytical results.

First, we compute collision/drop probability for a fixed number of channels $Nc = 50$, varying the number of admitted calls from 70 to 90.

We also fixed the total number of calls $N = 90$, varying the number of channels $Nc$ as illustrated in figure below.

![Fig. 7. Collision/drop probability Vs total number of calls](image)

![Fig. 8. Collision/drop probability Vs Number of Channels](image)

For an acceptable telephonic conversation, a maximum loss rate of 1% should be fixed [1] [4]. From obtained plots, we see that for about 1% collision/drop probability, the enhancement is about 15%.

In case of bad transmission conditions (e.g. noisy channel), error rate is increased and so collision/drop probability must be decreased ($P_{loss} = P_{error} + P_{drop/coll}$), hence the interest of PDSMA as it enhances collision probability of about 40% for a 0.5% collision rate and we see that it could be neglected for PDSMA when it is about 0.2% for pseudo-random schemes.

\(^1\) $\omega_{ns}$ values are: $\omega_{ns} = 0.27853; \omega_{ns} = 0.3245; \omega_{ns} = 2.1572; \omega_{ns} = 2.2222; \omega_{ns} = 1.0438; \omega_{ns} = 0.27853; \omega_{ns} = 0.79411; \omega_{ns} = 2.1572; \omega_{ns} = 2.2222; \omega_{ns} = 1.0438; \omega_{ns} = 0.79411;
To reduce collision probability, collided packets could be re-transmitted in the next frame. Then, a delay is added for medium access as the packet should wait the frame interval \( \tau \) for re-transmission. This added delay \( T \) depends on the number of re-attempts \( n \) and on the frame duration \( \tau \). However, \( n \) should be limited \((n \leq n_{\text{max}})\) according to the maximum allowed added delay: \( T \leq T_{\text{max}} = \tau n_{\text{max}} \).

Below, we express the probability \( \Pi \) of each maximum added delay value \( T = n \cdot \tau \).

\[
\Pi(T = n \cdot \tau) = \sum_{j=0}^{N_j} \sum_{i=0}^{n_{\text{coll}}} \pi_{i,j} \cdot P_{\text{coll} / i,j} \left( N_{\text{ac}} \geq 1 ; i, j \right) + \sum_{j=0}^{N_j} \sum_{i=0}^{n_{\text{coll}}} \pi_{i,j} \]

with \( 0 \leq n \leq n_{\text{max}} \).

Figure 9 below shows that, in case of \( n \leq 5 \) re-attempts which means an important maximum added delay of 100 ms, the enhancement is especially appreciable for 20 ms and 40 ms added delay values.

![Graph showing added access delay probability function](image)

**Fig. 9.** Added access delay probability function

We also computed the mean added delay \( E[T] \) due to collided packets re-transmission.

\[
E[T] = \tau \sum_{n=1}^{n_{\text{max}}} n \cdot \Pi(T = n \cdot \tau) \quad \text{[ms]}
\]

To evaluate the mean access delay, we fixed the maximum number of re-attempts after a collision to \( n_{\text{max}} = 1 \) which gives a maximum access delay of \( \tau \). Figure below shows the obtained mean access delays for \( N_c = 50 \) channels and \( \tau = 20 \text{ ms} \).

![Graph showing mean added access delay according to system load](image)

**Fig. 10.** Mean added access delay according to system load

From figure 10, we see that for 85 sources and 50 channels, PDSMA scheme decreases mean access delay from about 1.3 ms to 1 ms meaning an appreciable enhancement of about 30%.

Decreasing the loss rate and the access delay means an enhancement in call quality as perceived by user. For an identical QoS, it also means an increased capacity or a decreased blocking rate for user and in term of accepted telephonic calls and bandwidth utilisation for operator.

Those results show the interest of the proposed pseudo-deterministic access scheme which takes into account the fact that silent sources with an idle downlink are more likely to switch to ON state on the uplink. A simple pre-allocation distributed algorithm for channels access was used in this purpose.

V. CONCLUSION AND FUTURE WORK

We proposed in this paper a distributed algorithm for a pseudo-deterministic statistical multiple access. It is based on a pre-allocation scheme on uplink for silent voice sources. The main idea is to detect downlink activity which corresponds to the conversation partner activity to predict silent sources switching on the uplink; we used a 3-states voice model in this purpose. Performance evaluation section shows an appreciable enhancement in term of loss rate and access delay comparing to usual statistical voice packets schedulers. That means a better dimensioning and/or Call Admission Control (CAC) thanks to the bandwidth utilisation enhancement, especially in noisy channel.

In future work we will be interested in extending PDSMA scheme to data sources scheduling, especially for interactive (conversational) applications where downlink traffic (download) and uplink (upload) traffic are inter-dependant.

REFERENCES


