Delft University Of Technology
Faculty of Electrical Engineering
Telecommunications and Traffic-Control Group
Delft University of Technology
The Netherlands

Indoor Wireless Communications using Slotted ISMA protocols

N.R. Prasad

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Abstract

The performance of the Slotted ISMA protocols in Rician fading channel for Indoor Wireless communications considering Pico Cellular systems have been analyzed in this thesis. The throughput of Slotted nonpersistant Inhibit Sense Multiple Access (np-ISMA), Slotted 1-persistent ISMA (1p-ISMA) and Slotted np-ISMA\CD (Collision Detection) is investigated in the presence of n-interfering signals whose random amplitudes are considered as Rician distributed.
Numerical results are presented, indicating the effect of propagation impairments on channel capacity. The results are of importance for mobile networks and indoor wireless office communications.

Key words : ISMA, Rician fading, Non persistent, Collision and detection.

Summary

Inhibit Sense Multiple Access (ISMA) protocol has been investigated by the Telecommunication and Traffic control Systems group of Delft University of Technology in detail.

All the earlier studies have only considered Unslotted and Slotted Non-persistent ISMA. This thesis presents first time the performance analysis of Slotted 1-persistent ISMA (1p-ISMA) and Slotted Non-persistent ISMA with Collision Detection (np-ISMA\CD). The throughput has been derived for both protocols in Rician fading channel with capture effect. The traffic has been generated according to Poisson distribution.
The throughput of protocol Slotted 1-persistent ISMA\CD has also been derived.

The protocols have been compared and for low offered traffic in a Pico cellular system Slotted np-ISMA gives the best performance. Slotted np-ISMA\CD gives the same results depending on the values of the ratio of time taken by (user's standpoint) one transmission period with collision detection and the transmission time of a packet. Slotted 1p-ISMA gives the worst performance.

Contents

1. Introduction

The significance of the Information Age for communications networks is not so much that people will be communicating more with one another, but that we are constructing intelligent systems - factories, hospitals, banks and dozens of other intelligent economic modules - that will consume and generate information on a vast scale. The Information Age traffic will be increasingly:

1. Heterogeneous in terms of the original form of the message, mixing modes (data, voice, video), bandwidth, and other characteristics in a common traffic stream
2. subject to stringent error control to provide guaranteed quality of transmitted information
3. Rapidly evolving in format as the applications environment undergoes continuous technology change
4. Demanding flexible bandwidth
5. Semi-real-time and non-real-time communications will become much more important
6. Requiring high reliability and redundancy.

To be able to support the new systems, the orientation towards circuit-like communications, and requirement for efficient spectrum utilisation, we are mainly interested in what are called multiple-access architectures. Multiple-access systems are designed to allow a large number of users to share a common pool of radio-telephone circuits, much like the sharing of any other common or trunked network facility.

Wireless systems are bringing some new problems along. One of these faced today is that numerous users share the same communication channel which causes conflicts if several users want to transmit at the same time. Unlike the traditional networks, which make use of the point-to-point channels. These channels have non-interference feature, but this requires to be fixed which is not possible for wireless communication. So, to avoid interference in wireless systems there must be some regulation on how the available channel capacity is allocated to the users. These constitute multiple access protocols, through which users have to follow some rules in order to access the common channel. A need for multiple access protocol arises when the network is accessed by more than one independent users. This causes conflict. Multiple access protocol can avoid or try to resolve these conflicts. To avoid the conflicts, protocol will have to give every user their own resources. Thus multiple access protocol used in the communication systems in this report shares the resources in the channel. In this case the two main reasons to share the resources among the users are:

1. the resources are scarce and/or expensive,
2. a need for a user to be able to communicate with all the other users, e.g. telephone system.

In 1970, the very first multiple access protocol was developed at the university of Hawaii (the ALOHA [10]). Since then many new protocols have been developed. Some of them are Code Division Multiple Access (CDMA), Slotted ALOHA, CSMA (Carrier Sense Multiple Access), ISMA, PRMA (Packet Reservation Multiple Access), etc.

1.1 Classification of MA protocols

Numerous ways have been suggested to divide these protocols into groups [16]. The MA-protocols can be classified into two groups see figure 1.1: contentionless protocols and contention protocols.

Contentionless (or scheduling) protocols avoid situations where two or more users access the channel simultaneously by scheduling the transmissions of the users. This is done either in a fixed style where each user is allocated part of the transmission capacity, or in a demand assigned fashion where the scheduling only takes place between the users that have something to transmit.
The scheduling has two forms:

1. Fixed assignment: the available channel capacity is divided among the users in such a way that each user is allocated a fixed part of capacity, independent of its activity. Division can be done in time and frequency. Time Division Multiple Access (TDMA) is the result of time division where time is divided into frames and each user is assigned to a fixed

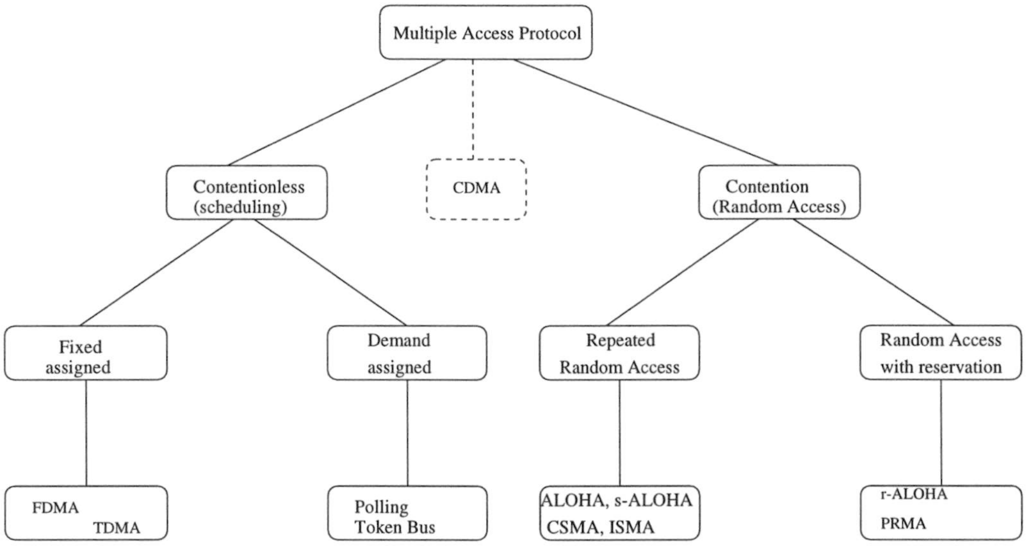

Figure 1.1: Classification of Multiple Access Protocols.

part of each frame without any overlapping. Frequency Division Multiple Access (FDMA) is the result of frequency division where channel bandwidth is divided into non-overlapping frequency bands and each user is assigned a fixed band.

2. Demand assignment: this can be further divided into centralised and distributed control. With centralised control there is a single entity that schedules the transmissions, for example the Roll-Call Polling protocol. With distributed all users are involved in the scheduling process and an example of such a protocol is the Token-Bus protocol.

With contention (random) protocols there is no scheduling of transmissions. The protocol must resolve conflicts once they occur. Thus, the user may or may not know of any ongoing transmissions. So, if the users transmit more or less at the same time then all the transmissions will fail. This protocol can be subdivided in two groups. The repeated random access protocols (ALOHA, s-ALOHA, CSMA and ISMA) and the random access protocols with reservation (r-ALOHA and PRMA).

Repeated Random Access Protocols

When a user starts transmitting, he/she does not know if there are other users also transmitting at the same time. Thus contention may occur. Contention may occur when users can not detect an ongoing transmission and try to start a new transmission. The protocols belonging to this group are pure or p-ALOHA, slotted or s-ALOHA, Carrier Sense Multiple Access (CSMA) and Inhibit Sense Multiple Access (ISMA). With CSMA protocols, user senses the channel before transmitting, where as with ISMA protocols base station inhibits the transmission if the channel is busy or idle. Yet collisions may occur due to propagation delay.

Random Access with reservation

When a user has a row of packets to transmit the transmission of the first packet is done in the same manner as every packet in pure random access protocol is transmitted. Once the first transmission is successful (random process) a fixed part of the channel capacity is allocated to the user for the transmission of the rest of the packets, the user gets a reservation. Other users are thus aware of the parts of the channel allocated to the reserved users so the transmissions are carried out without contention. The transmissions are scheduled.
After a successful transmission of all the packets, the user returns the allocated capacity so the other users can use it.

The protocols that fall in this category are reservation or r-ALOHA using slotted ALOHA as random access method to obtain reservation and PRMA.

Recently Code Division Multiple Access has become very hot topic in the field of multiple access protocols. CDMA is classified as the third type of protocol and placed between Contentionless and Contention protocols.

1.2 Cellular Systems and Performance Measures

Since the demand for mobile communication is still increasing very rapidly, it is necessary to maximise the number of users that can be simultaneously active in one cell, in order to keep the number of cells, and therefore the costs as limited as low as possible. Thus to know which protocol performs good under different operating conditions. Therefore, by comparing the performances in different environments of these MA (multiple access) protocols , one can make a sensible decision on when to use which protocol.
It is not possible to compare the protocol performance in every environment

because there are too many of them. So, one must make a choice between these environment to make the comparison possible. This has been done in further paragraphs.
The performance of a MA protocol strongly depends on the environment in which the protocol operates. The type and number of users, the type of channel, the size of the system etc. are only the few parameters describing the environment, but not enough to show that it is impossible to compare the performance of the protocols in all possible environments.
The performance of the protocols can be calculated in a cellular environment. Cellular Environment is usually divided into three different cell-types based on the diameter of the cell: Pico cells (the diameter lies from 20 to 200 m), micro cells (from 200 m to 2 km) and macro cells (2 km to 20 km). The performance comparison will be done in these three different cellular environment. One can make some general assumptions applying to these environments. They are :

1. The cells are hexadiagonal in shape. In the middle of each cell there is a base station with number of users.

2. An ideal, noiseless multiple access channel is assumed. The signal transmitted via the channel suffers only from propagation delay and attenuation.

3. User or base station is assumed to receive a packet perfectly if the carrier to interference ratio (C/I) is above a certain threshold. Below this they will not be able to receive the packet [18].

4. The total bandwidth available to the system is 22 MHz. 22 MHz at 1 bit/hz gives a total available bit-rate C_c (channel capacity) of 22 $Mbit/s$ of which each cell is allocated C_c/K $Mbit/s$ where K is number of cells in a cluster. This can be calculated by using $\frac{C}{I} = \frac{\sqrt{3K^{\gamma}}}{6}$. Here γ is the propagation attenuation slope or path loss exponent.

5. The users transmit fixed length packet.

6. All users are equal and each user generates packets according to a Poisson process with parameter λ. In speech communication, each user generates digital speech at 32 kbit/s (DECT).

Pico cells:

- Used for environments like factories, offices, shopping complexes, small stores, houses etc.
- diameter of the cell lies between 20 and 200 m.
- This results in maximum propagation delay from a user to the base station of 0.66 μs.
- The propagation attenuation slope γ depends on the material and architecture of the building.

Micro cells:

- used in outdoors urban areas, industrial plants, airports etc., also where there is heavy traffic demand.
- Cell diameter is between 200 m and 2 km.
- Maximum propagation delay for the chosen diameter from user to the base station is 6.6 μs.

Macro cells:

- Used to cover suburban areas, rural areas etc., also in areas with restricted traffic demand.
- diameter falls between 2 km and 20 km.
- This diameter results in a maximum propagation delay from user to base station of 66 μs.

Performance Measures

The two most commonly used performance measures are channel throughput and packet delay. In addition, stability of the protocol, maximum number of users per cell and spectrum efficiency are also important parameters.
For channel throughput, packets can be differentiated in two types: 1) information packets which contains the original data that a user wants to transmit, 2) control packets, needed for correct operation of the protocol. *Channel Throughput* is defined as the average number of successfully transmitted information packets per time unit divided by the maximum number of packets that can be successfully transmitted over the channel in the same time. Channel throughput can be calculated both as the function of the number of users and as a function of the average normalised total generated traffic G.
The *packet delay* is defined as the average time between the beginning of transmission of a packet and the successful reception of this packet by the transmission. Packet delay consists of three parts:

1. the time a packet has to wait in the buffer before it is successfully transmitted

2. the time needed to transmit the packet

3. the propagation time it takes the packet to reach the destination.

There are two definitions to evaluate *stability*:

1. When a change in the traffic load on the channel occurs, the protocol stays stable if it converges without excessive oscillations to a non-zero equilibrium

2. if the average delay is bounded then a protocol is considered to be stable.

The final performance measure will be *Spectrum Efficiency* (SE). This measures the performance of the bandwidth used. Spectral efficiency is given as a maximum traffic load per unit of frequency per unit area for a given maximum blocking probability [5] and given by

$$SE = R_{BW} \frac{P_{cap}(z_0)}{sC_u} \frac{L - H}{L} \tag{1.1}$$

where $P_{cap}(z_0)$ is the capture probability with z_0 is the capture ratio, s is the cell area, R_{BW} represents the bit rate to bandwidth ratio, L is the packet length and H is the length of header. The number of data bits per packet is $L - H$.

1.3 Scope of the Report

Different types of ISMA has been looked into in this report for indoor wireless communications. Chapter 2 describes the propagation model of the system. Slotted Non-Persistent ISMA, Slotted 1-Persistent ISMA, Slotted Non-Persistent ISMA\CD and Slotted 1-Persistent ISMA\CD has been investigated in chapter 3. Chapter 4 shows the performance analysis of these protocols in Rician fading channel with computation results. The comparisons of the ISMA protocols have been presented in chapter 5. Finally, chapter 6 gives the conclusions and recommendations.

2. Propagation Model

One of the main reasons for the interest in indoor wireless communication is the need for mobility of personnel. The problem which will arise due to this is the capacity of the system. Using the model of F. van der Wijk [6], a measure for the throughput of the protocol can be determined using Rician desired plus n Rician interferers.

The model considers the situation where terminals communicating with a centrally located base station using packet radio. During communication, terminals compete with each other to get access to the common channel, thus giving a reason to investigate, which multiple access protocols are suited for this required situation.

The rooms of 19th and 20th floors of Electrical Engineering, Delft University of Technology, The Netherlands, has been considered for this investigation. The rooms are located on the both sides of 65 m long and 2 m wide, straight corridor. Each room is 4 m wide, 6 m long and 2.80 m high. These rooms are separated by a wall made of plaster board, rock wool and steel frames. The separating wall of the corridor and rooms is made of bricks. The floor is made of enforced concrete of 50 cm and above the doors of each room, at the height of 2.10 m, a glass window runs up to the ceiling. There is an open stairway on the both end of the corridor leading to the upper and lower floors. Each room has been considered a cell, with a centrally located base station using packet radio.

The investigation includes the channel where the test terminal (T) and the interfering terminals (i) are within a cell (see figure 2.1), so the signals coming from both the test terminal and the interfering terminals are Rician distributed.

2.1 Propagation Parameters

Capture

During the transmission from a mobile user to the base station, interference may occur. Interference may come from other users in the cell and outside the cell. Development of packet communication has been largely based on the

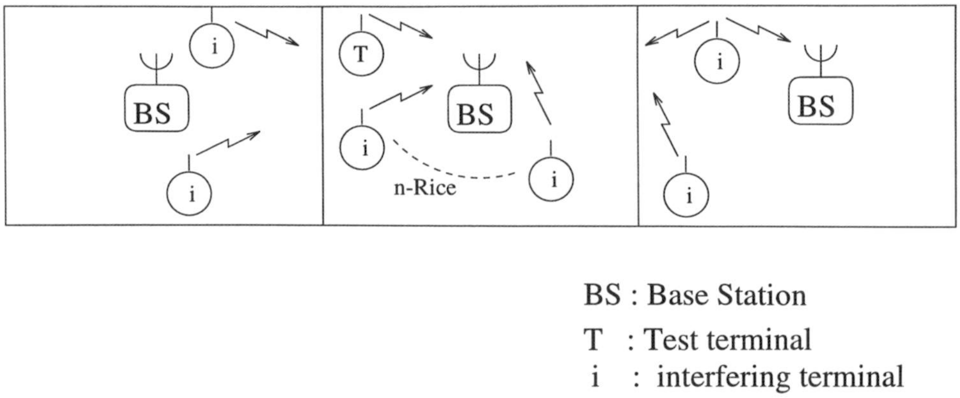

Figure 2.1: Cell Structure.

assumption that when two packets interfere, both will be lost. This problem can party be solved by using capture. A radio receiver can capture a desired packet in the presence of n-interfering packets, if the power of the desired packet P_s sufficiently exceeds the joint interfering packet power P_n during a certain time slot.

Fading

The envelope of the received signal in a mobile environment fluctuates due to the obstacles between receiver and transmitter. This effect is called fading. In a indoor environment, the transmitted signal will be reflected from the different walls and hence arrive at different times with different phases at the receiver . There is sometimes direct line of sight path. The fast varying amplitude is described by Rician pdf [6]

$$f(A) = \frac{A}{\sigma^2} \exp\left[-\frac{A^2+S^2}{2\sigma^2}\right] I_o\left[\frac{SA}{\sigma^2}\right] \qquad \text{where } 0 \leq A < \infty \qquad (2.1)$$

where A is the signal amplitude, σ^2 is the average power of the scattered signal and S is the peak value of the received line of sight signal.

2.2 Indoor Wireless Communication Channel

The terminals are assumed to be in one room of the 19th or 20th floor with a base station in the center. The amplitude of the signals can be modelled by Rician pdf (probability density function) as given in eq.(2.1)
From eq. (2.1) the pdf of the fast varying instantaneous power, $p = A^2/2$, is

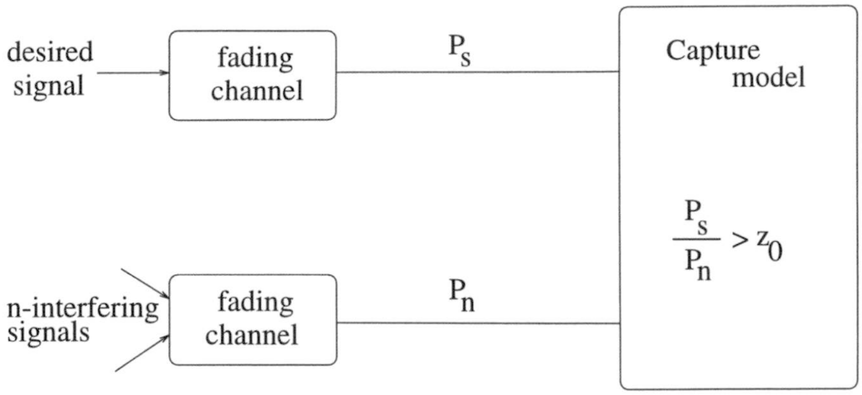

Figure 2.2: The capture model.

found as

$$f(p) = \frac{1}{\sigma^2} \exp\left(-\frac{2p + S^2}{2\sigma^2}\right) I_0\left(\frac{\sqrt{2p}S}{\sigma^2}\right) \tag{2.2}$$

This can also be written as

$$f(p) = \frac{K+1}{p_0} \exp\left(-\frac{K+1}{p_0}p - K\right) \times I_0\left(2\sqrt{\frac{K^2+K}{p_0}p}\right) \tag{2.3}$$

where $p_0 = \frac{(S^2+2\sigma^2)}{2}$ is the local mean power and K is the Rice factor, which is defined as the ratio of the average power of the dominant multipath component and the average fading power received over he non-dominant paths,

$$K = \frac{S^2}{2\sigma^2} \tag{2.4}$$

2.3 Composite pdf of N-Rician signal

In this section the pdf of the N Rician fading interferers have been investigated. The model used for the calculations is shown in figure 2.2.

The derivation of the pdf for N convolved Rician fading channel is as follows

Derivation 1 :
It is shown here that Rice pdf is a transformation of the joint pdf of two Gaussian variables.

Two Gaussian variables x and y have been taken with :

$$\text{parameters} \quad \begin{aligned} \mu_x &= K^2\cos(\phi) \\ \mu_y &= K^2\sin(\phi) \\ \text{var}x &= \text{var}y = K^2 \end{aligned}$$

Let R be : $R = \sqrt{x^2+y^2}$ After calculating the pdf of R, it shows that it is same as a Rician pdf:

$$f(x,y;\phi) = \frac{1}{2\pi K^2}\exp\left(-\frac{(x-K^2\cos(\phi))^2+(y-K^2\sin(\phi))^2}{2K^2}\right) \tag{2.5}$$

which is equal to

$$f(x,y;\phi) = \frac{1}{2\pi K^2}\exp\left(-\frac{x^2+y^2-2K^2(x\cos(\phi))+(y\sin(\phi))+K^4}{2K^2}\right) \tag{2.6}$$

Now polar coordinates are introduced : $\begin{aligned} x &= R\cos(\beta) \\ y &= R\sin(\beta) \\ dxdy &= Rdrd\beta \end{aligned}$

Thus giving us

$$f(R,\beta,\phi) = \frac{R}{2\pi K^2}\exp\left(-\frac{R^2-2K^2R\cos(\phi-\beta)+K^4}{2K^2}\right) \tag{2.7}$$

Integrating this equation over β gives $f(R)$

$$f(R) = R\exp\left(-\frac{R^2+K^4}{2K^2}\right)\frac{1}{2\pi K^2}\int_0^{2\pi} exp(R\cos(\phi-\beta))d\beta \tag{2.8}$$

The modified Bessel Function of the first kind and zero order has been defined as :

$$I_0(x) = \frac{1}{2\pi}\int_0^{2\pi} exp(x\cos(\phi-\beta))d\beta \tag{2.9}$$

By using this equation

$$f(R) = \frac{R}{K^2}\exp\left(-\frac{R^2+K^4}{2K^2}\right)I_0(R) \tag{2.10}$$

Using $v = \frac{R}{K}$, $dR = Kdv$, the normalised Rician pdf is

$$f(v) = v\exp\left(-\frac{v^2+K^2}{2}\right)I_0(vK) \tag{2.11}$$

Derivation 2 :
Now the characteristic function of this Rice pdf has been derived.
Fourier transformation can be defined as :

$$h_x(z) = \int_{-\infty}^{\infty} f(x) \exp(-izx) dx \tag{2.12}$$

with inverse transformation

$$f(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} h_x(z) \exp(-izx) dz \tag{2.13}$$

For the calculation of the characteristic function :
$L = R^2$, R as in step 1. Thus $L = x^2 + y^2$.
Thus the characteristic function of L is the product of x^2 and y^2. By this the following properties of the fourier transformation can be used

$$h_{f(x)}(z) = \int_{-\infty}^{\infty} p(x) \exp(-izf(x)) dz \tag{2.14}$$

the characteristic function of x^2 is :

$$h_{x^2}(z) = \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi K^2}} \exp\left(\frac{(x - K^2\cos(\phi))^2}{2K^2} - izx^2\right) dx \tag{2.15}$$

This integral has been investigated in [3] and the solution is :

$$h_{x^2}(z) = \frac{1}{\sqrt{1 - 2\pi izK^2}} \exp\left(\frac{iK^4\cos^2(\phi)z}{1 - 2iK^2z}\right) \tag{2.16}$$

Same can be done for y^2 and thus by multiplying these two gives L's characteristic function

$$h_L(z) = \frac{1}{1 - 2\pi izK^2} \exp\left(\frac{iK^4z}{1 - 2iK^2z}\right) \tag{2.17}$$

Inverse Fourier transform of $h_{x^2}(z)$ is given in [3] :

$$f(L) = \frac{1}{2K^2} \exp\left(-\frac{L + K^4}{2K^2}\right) I_0(\sqrt{L}) \tag{2.18}$$

After $v^2 = \frac{L}{K^2}$, $dL = 2K^2vdv$ equation (2.17) becomes

$$f(v) = v \exp\left(-\frac{v^2 + K^2}{2}\right) I_0(Kv) \tag{2.19}$$

Derivation 3 :
Now we find the expression for the composite pdf of N-Rician signals by deriving the Fourier transformation of the Rice pdf till power N and the executing of the inverse Fourrier transformation.

From the theory of Fourier, a convolution in time domain is a multiplication in frequency domain. So the Fourier transformation of N convolved normalised Rician pdf's with Rice factor K is :

$$(h_L(z))^N = \frac{1}{(1-2\pi izK^2)^N}\exp\left(\frac{NiK^4z}{1-2iK^2z}\right) \tag{2.20}$$

with inverse Fourier transformation :

$$f(L) = \frac{1}{2K^2}\left(\frac{L}{NK^4}\right)^{\frac{N-2}{2}}\exp\left(-\frac{L+NK^4}{2K^2}\right)I_{N-1}(\sqrt{LN}) \tag{2.21}$$

After the following transformation: $X = \frac{L}{K^2}$, $dL = K^2dx$

$$f(X) = \frac{1}{2\sigma^2}\left(\frac{X}{P}\right)^{\frac{N-2}{2}}\exp\left(-\frac{X+P}{2\sigma^2}\right)I_{N-1}\left(\frac{\sqrt{XP}}{\sigma^2}\right) \tag{2.22}$$

Plots for different values of N and K are given in figure 2.3

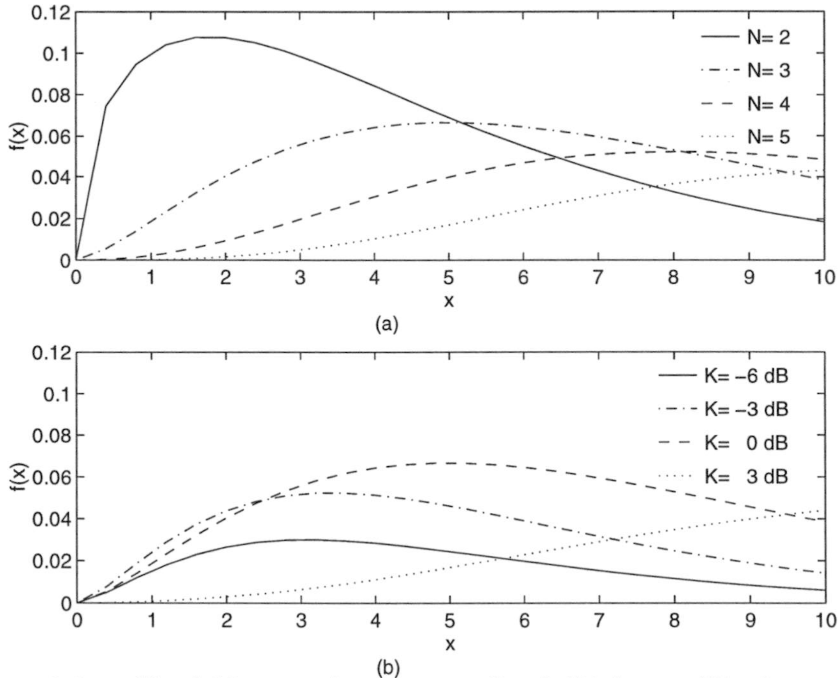

Figure 2.3: pdf of N convolved normalized Rician pdf's for $K = 0$dB, $N = 3$.

3. ISMA

With Inhibit Sense Multiple Access protocols (ISMA) [9] each user must be able to detect the transmission of all other users. With ISMA there is a base station that transmits a busy/idle signal on a separate channels (inbound and outbound) to indicate the presence or absence of a transmission of one of the users. As soon as the base station receives a transmission from a user on the inbound channel, it will generate a busy signal on the outbound channel. When the transmission ends, the base station transmits an idle signal. Now if two users are hidden from each other but not from the base station they will still be able to determine if the other user is transmitting or not.
The variations on the ISMA scheme are due to the behaviour of users that wish to transmit and find (by sensing) the channel busy. Different variations of ISMA will be analysed in this chapter.

3.1 Slotted Non-persistent ISMA

We assume that all terminals have the same characteristics, except their relative positions. Data Packets arrive at the terminals generated by the users. The transmission occurs only when the terminal gets permission to transmit. When there is a busy signal, transmission attempts are unsuccessful (see figure 3.1). Such packets are rescheduled for later by putting them into retransmitting buffer, which will transmit again at the start of the next idle time slot and the duration of a time slot is assumed to be exactly to the transmission time of a single packet. Thus, there is either no collision or complete collision of the packets. Since there is no collision detection, a higher level process is needed to determine which packets were lost due to this complete collision and need to be retransmitted.

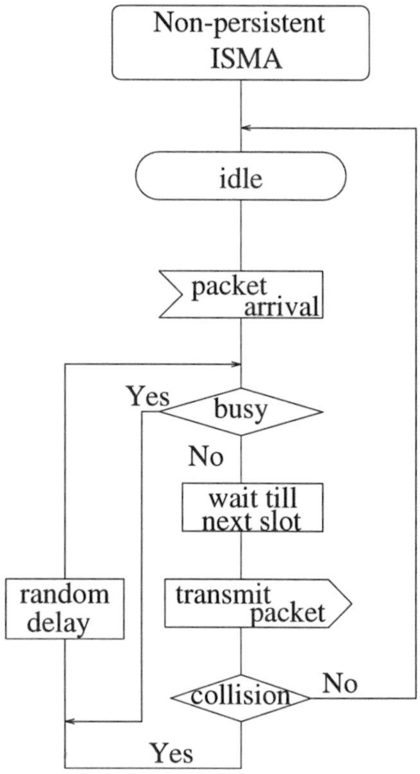

Figure 3.1: Terminal transmission of Slotted Non-persistent ISMA protocol.

A terminal in the blocked state will listen to the busy signal transmitted by the base station to determine when the channel becomes idle.

Throughput Analysis

Each terminal of slotted np-ISMA is restricted to start transmission only at the beginning of a time slot and the duration of a time slot is assumed to be exactly to the transmission time of a single packet. Thus, there is either no collision or complete collision of the packets in which case an unsuccessful packet will be subsequently retransmitted after a random number of slots. In order to prevent these collisions among data packets transmitted from mobile terminals to common base station, the inbound multiple access channel can be supplemented by a broadcast inhibit-signalling channel. The inhibit bits indicate the state of the inbound channel: busy or idle. The moment when the base station receives an inbound packet, the outbound signalling channel broadcasts the busy condition to all terminals. A fraction of the constant packet length is needed to inhibit the mobile packet transmissions,the inhibit delay fraction d, a dimensionless quantity. Thus mobile terminals

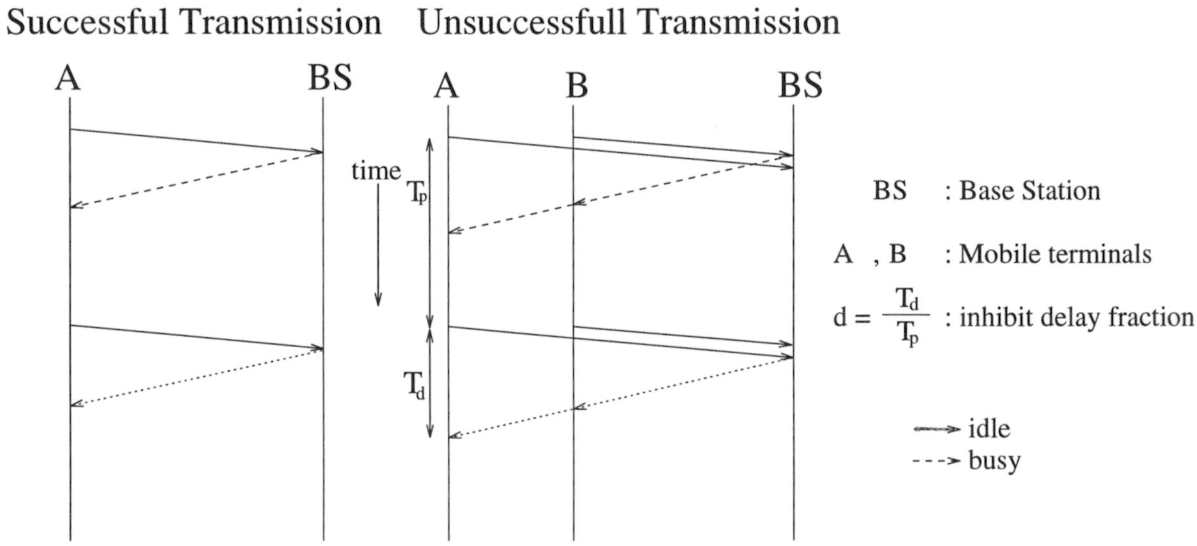

Figure 3.2: Slotted Non-persistent ISMA packet timing

are inhibited from transmission until the inbound channel is free, thus preventing collisions. These packets are rescheduled according to retransmission distribution [15, 4]. The successful and unsuccessful transmissions in ISMA are illustrated in figure 3.2. Inhibit delay fraction is shown in the figure by notation d, ratio of propagation delay (T_d) and packet tim ing (T_p).

From figure 3.2, the length of an idle period is at least one time slot. When the idle period is only one slot long, it means there is at least one arrival in the first slot of the idle period. For the period to be two slots long means that there is no arrival at the first slot, but there is at least one arrival in its second slot. Continuing the reasoning and considering the Poisson scheduling process we have :

$$I = \frac{d}{1 - \exp(-dG)} \tag{3.1}$$

A collision might occur if two or more packets arrive within the same slot and are scheduled for transmission in the next slot. A busy period will contain k transmission periods if there is at least one arrival in the slot of each of the first $k-1$ transmission periods, and no arrival in the last slot of the k^{th} transmission period. Thus, the busy period is

$$B = \frac{1 + d}{\exp(-dG)} \tag{3.2}$$

The expected useful time is found as:

$$U = \frac{B}{1+d} P_{\text{suc}} \tag{3.3}$$

where P_{suc} is the probability of a successful transmission period. We have:

$$P_{\text{suc}} = \frac{Prob[\text{ single arrival within a slot }]}{Prob[\text{ more arrivals with in a slot }]} \tag{3.4}$$

$$P_{\text{suc}} = \frac{dG \exp(-dG)}{1 - \exp(-dG)} \tag{3.5}$$

Putting all these together we get the throughput

$$S = \frac{dG \exp(-dG)}{1 + d - \exp(-dG)} \tag{3.6}$$

3.2 Slotted 1-persistent ISMA

In np-ISMA there are situations in which the channel is idle although one or more users have packets to transmit. The 1-persistent ISMA (1p-ISMA) is alternative to np-ISMA that avoids such situations. When the outbound channel sends the busy signal to the terminal, it persists to wait and transmits as soon as the channel becomes idle (see figure 3.3). Thus the channel is always used if there is a user with a packet.

Throughput Analysis

The analysis of slotted 1p-ISMA is similar to slotted np-ISMA. The mean of idle period is same as in slotted np-ISMA (figure 3.2). Since the busy period will contain k transmission periods if at least one packet arrives in each of the first $k-1$ transmission periods and no packets arrives in the k^{th} transmission period. So the busy period B is

$$B = \frac{1+d}{\exp(-G(1+d))} \tag{3.7}$$

The probability of success in the first transmission period in a busy period, P_{suc_1}, is different from the success probability in any other transmission period within the busy period, P_{suc_2}. For the first transmission period in a busy period to be successful we need the last slot of the idle period to contain

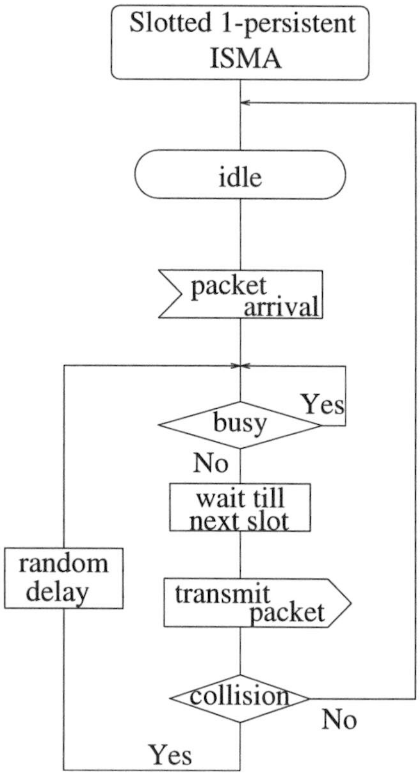

Figure 3.3: Terminal transmission of Slotted 1-persistent ISMA protocol.

exactly one arrival, taking in account that there is at least one arrival there, since it is the last slot. Hence,

$$P_{\text{suc}_1} = \frac{dG \exp(-dG)}{1 - \exp(-dG)} \tag{3.8}$$

For any transmission period in a busy period to be successful we must have exactly one arrival during the previous transmission period,

$$P_{\text{suc}_2} = \frac{G(1+d) \exp(-G(1+d))}{(1 - \exp(-G(1+d))} \tag{3.9}$$

The channel carries useful information only during successful transmission periods. P_{suc_1} is the expected amount of time the channel carries useful information during these period and P_{suc_2} is the probability of success in each of these transmission periods. The expected amount of time within a cycle that the channel carries useful information is

$$U = P_{\text{suc}_1} + \frac{B - (1+d)}{1+d} P_{\text{suc}_2} \tag{3.10}$$

Therefore the throughput can be given by

$$S = \frac{G\exp\left(-(1+d)G\right)(1+d-\exp\left(-dG\right)}{(1+d)(1-\exp\left(-dG\right))+d\exp\left(-(1+d)G\right)}. \tag{3.11}$$

3.3 Slotted ISMA with Collision Detection

In this group of protocols the throughput is the ratio between the expected useful time spent in a cycle to the cycle duration itself. To improve the throughput, the cycle length must therefore be reduced. A cycle is composed of a transmission period followed by an idle period. Shortening the idle period is possible by means of 1-persistent ISMA protocols, which do not perform very well under most loads. The duration of the successful transmission periods should not be changed for this is the time the channel is used best. Hence, performance can be improved by shortening the duration of unsuccessful transmission periods.
In all ISMA protocols, a transmission that is initiated when the inbound channel is idle, the outbound channel sends an idle signal which reaches all the users after at most one inhibit delay fraction, d. Beyond this time, the inbound channel is sensed busy. Figure 3.4 describes the behaviour of the Slotted ISMA\CD protocols when a collision occurs.

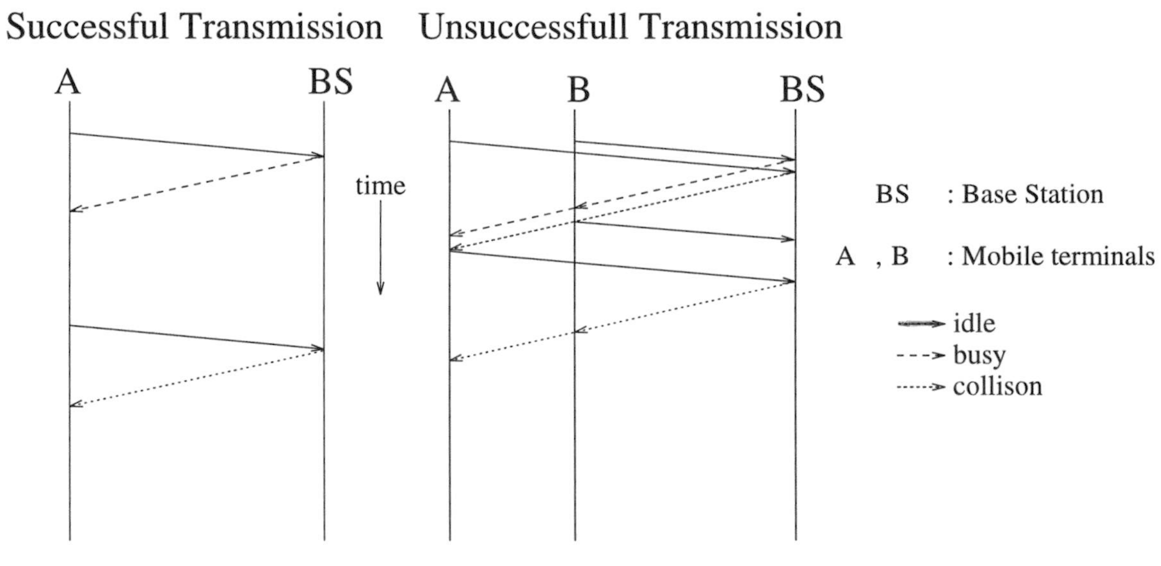

Figure 3.4: Collision Detection Timing

3.3.1 Slotted Non-persistent ISMA\CD

The operation of Slotted ISMA\CD protocols is identical to the operation of the corresponding ISMA protocols, expect that if a collision is detected during transmission by the base station, the transmission is aborted and the packet is scheduled for later transmission (see figure 3.5) .

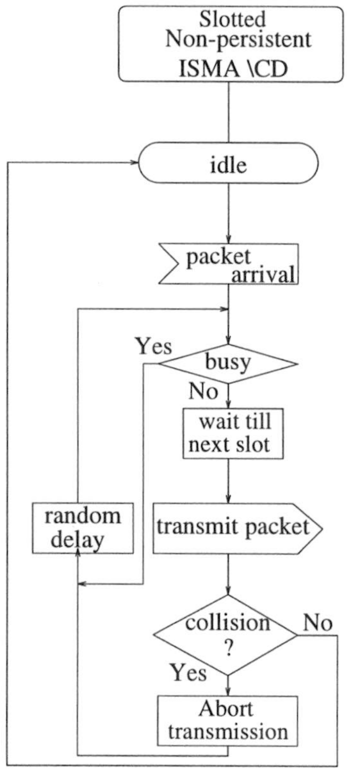

Figure 3.5: Slotted np-ISMA\CD

Throughput Analysis

The non-persistent ISMA\CD time alternates between busy periods (which includes both successful and unsuccessful transmission periods) and idle periods. The length of the busy period is B (see figure 3.6)

$$B = \frac{P_{suc}(1+d) + (1-P_{suc})(\gamma + d)}{\exp(-dG)} \tag{3.12}$$

where P_{suc} is the probability of a successful transmission period

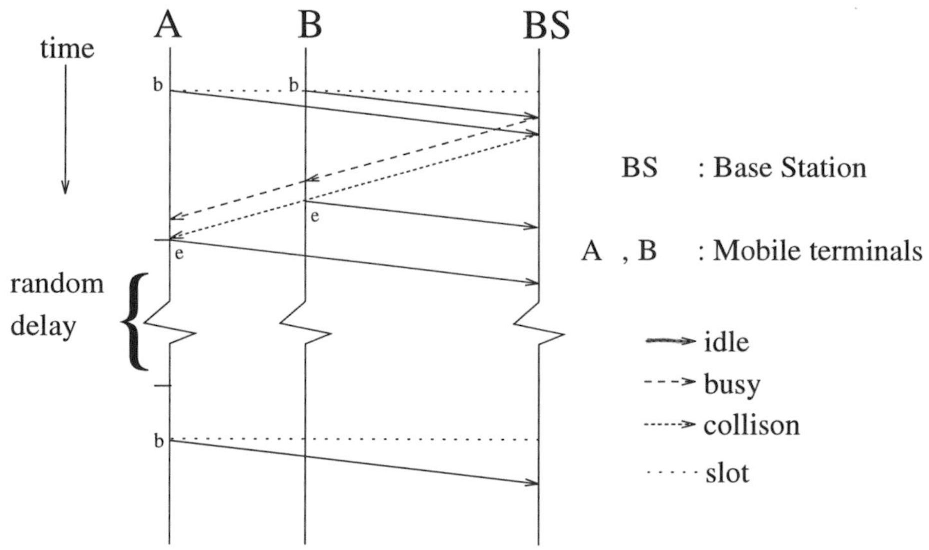

Figure 3.6: Slotted np-ISMA\CD Packet Timing

$$P_{suc} = \frac{Gd\exp(-dG)}{1-\exp(-dG)} \tag{3.13}$$

and γ is the time taken to complete a successful transmission of a user.

$$\gamma = 2d + d_{CD} + d_{cr} \tag{3.14}$$

d_{CD} is the time taken by the base station to detect a collision and d_{cr} is the time taken to let the other users know that a collision took place.

The distribution of the idle period is identical to that computed for Slotted np-ISMA , thus the expected length of the idle period is

$$I = \frac{d}{1-\exp(-dG)} \tag{3.15}$$

Amount of time within a cycle during which the channel carries useful information is

$$U = \frac{P_{suc}}{\exp(-dG)} \tag{3.16}$$

Combining the equations throughput can be analysed

$$S = \frac{U}{B+I} = \frac{dG\exp(-dG)}{dG\exp(-dG) + (1-\exp(-dG) - dG\exp(-dG))\gamma + d} \tag{3.17}$$

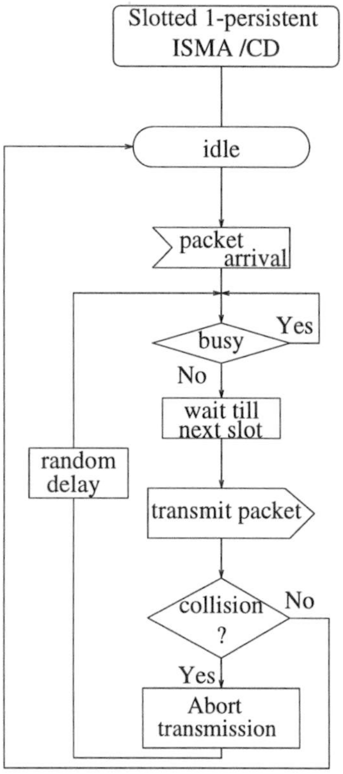

Figure 3.7: Terminal transmission of Slotted 1p-ISMA\CD

$\gamma = 1$, throughput is identical to Slotted np-ISMA.

3.3.2 Slotted 1- persistent ISMA\CD

The operation of this protocol is similar to that of 1p-ISMA, expect that if a collision is detected during transmission by the base station, the transmission is aborted and the packet is scheduled for later transmission (see figure 3.7).

Throughput Analysis

With the 1-persistent ISMA\CD the time also alternates between busy periods (containing successful and unsuccessful transmission periods) and the idle periods, and a cycle in a busy period followed by an idle period (see figure 3.8). Notice that here a success or failure of a transmission period is the busy period depends (only) on the length of the preceding transmission period, except for the first transmission period that depends on the arrivals during the preceding slot.

With the average length of an idle period is $d/(1 - \exp -dG)$, the throughput is given by [16]

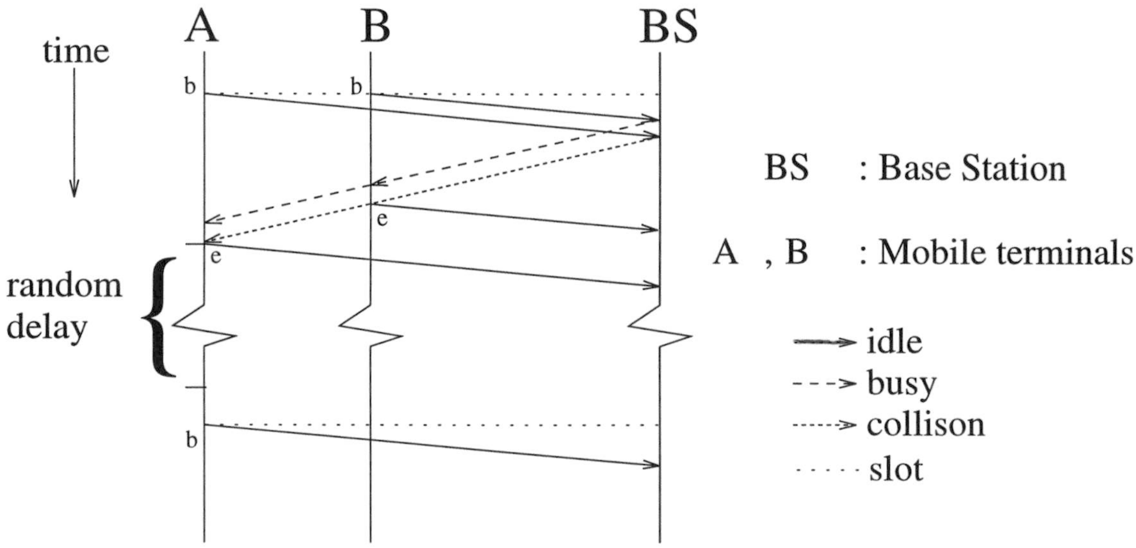

Figure 3.8: Slotted 1p-ISMA\CD Packet Timing

$$
\begin{aligned}
S &= \frac{U}{B+I} \\
&= \frac{U(d)}{B(d) + \frac{d}{1-\exp(-dG)}} \qquad (3.18)
\end{aligned}
$$

The derivation of this throughput is provided in Appendix A.

4. Performance Analysis in indoor Rician fading channel

4.1 Packet success Probability

In this section packet success probability with the capture-model is derived for Slotted np-ISMA, Slotted 1p-ISMA, Slotted np-ISMA\CD and Slotted 1p-ISMA\CD.

4.1.1 Slotted np-ISMA with capture

If there is more than one transmission, all packets will be destroyed because of overlapping. This section has more realistic model compared to the one given in section 3.1.
When data packets competing for access to a common radio receiver arrive from different distances and with independent fading levels, it is no longer certain that all colliding packets will always be annihilated by each other.
It is assumed that there is a test packet and n interfering packets. If the power of the former (P_s) sufficiently exceeds the joint interfering power (P_n) during a certain section of time slot, capture is assured.
So, the test packet is destroyed in a collision if (and only if)

$$\frac{P_s}{P_n} < z_0 \qquad \text{during } t_w \text{ with } n > 0 \tag{4.1}$$

with z_0 is the capture ratio.

The probability of being able to capture the receiver in an arbitrary time slot is

$$P_{cap}(z_0) = \sum_{n=1}^{N} R_n[1 - Prob\{\frac{P_s}{P_n} < z_0\}] \tag{4.2}$$

where N is number of users in one cell (eg. $N = 10$ maximum) and R_n is the probability of n interfering packets overlapping a test packet.

$$R_n = \frac{(dG)^n}{n!} \exp(-dG) \tag{4.3}$$

Using the capture probability, expected useful time is found as

$$U = \frac{B}{1+d} P_{suc} \tag{4.4}$$

taking the capture effect in cosideration, probability of a successful transmission period is

$$P_{suc} = \frac{dG}{1+d-\exp(-dG)} \sum_{n=1}^{N} R_n[1 - F_{z_n}(z_0)] \tag{4.5}$$

Finally,the channel throughput can be stated as

$$S = \frac{dG \exp(-dG)}{1+d-\exp(-dG)} \sum_{n=1}^{N} R_n[1 - F_{z_n}(z_0)] \tag{4.6}$$

with distribution function, $F_{z_n}(z_0) = Prob\{\frac{P_s}{P_n} < z_0\}$
Defining the signal to interference ratio for the packet and n contenders

$$z_n = \frac{P_s}{P_n} \tag{4.7}$$

and the random variable

$$W = P_n \tag{4.8}$$

the two-dimensional p.d.f.

$$f_{z_n,W}(z, W) = f_{P_s,P_n}(P_s, P_n) \left| \frac{\partial(p_s, p_n)}{\partial(z, W)} \right| \tag{4.9}$$

Through stochastic independent P_s and P_n, this becomes

$$f_{z_n,W}(z, W) = f_{P_s}(zW) f_{P_n}(W) W \tag{4.10}$$

so the p.d.f. for z_n

$$f_{z_n}(z) = \int_0^{\infty} f_{P_s}(zW) f_{P_n}(W) W dW \tag{4.11}$$

and the corresponding distributed function

$$F_{z_n}(z_0) = \int_0^{z_0 dz} \int_0^{\infty} f_{P_s}(zW) F_{P_n}(W) W dW \tag{4.12}$$

4.1.2 Slotted 1p-ISMA with capture

Using the capture effect on the results derived in section 3.2, the probability of a successful transmission period in a busy period is

$$P_{\text{suc}_1} = \frac{dG \exp(-dG)}{1 - \exp(-dG)} \sum_{n=1}^{N} R_n [1 - F_{z_n}(z_0)] \tag{4.13}$$

and the success probability in any other transmission period with the busy period is

$$P_{\text{suc}_2} = \frac{G(1+d) \exp(-G(1+d))}{(1 - \exp(-G(1+d))} \sum_{n=1}^{N} R_n [1 - F_{z_n}(z_0)] \tag{4.14}$$

Thus giving the throughput for the Slotted 1p-ISMA with capture

$$S = \frac{G \exp(-(1+d)G)(1 + d - \exp(-dG)}{(1+d)(1 - \exp(-dG)) + d \exp(-(1+d)G)} \sum_{n=1}^{N} R_n [1 - F_{z_n}(z_0)]. \tag{4.15}$$

4.1.3 Slotted np-ISMA\CD with capture

Taking capture effect into consideration, means that the colliding packets will not always be destroyed, but will have a certain probability of being received successfully by the receiver.

The throughput of Slotted np-ISMA\CD with capture is defined as ration of the probability of success of the test packet, and expected length of the cycle assuming that there is N population of users with the total arrival rate of packets, G.

Thus the throughput is

$$S = \frac{U}{B+I} = \frac{dG\exp(-dG)}{dG\exp(-dG) + (1-\exp(-dG) - dG\exp(-dG))\gamma + d} \cdot$$
$$\sum_{n=1}^{N} R_n[1 - F_{z_n}(z_0)]. \tag{4.16}$$

4.1.4 Slotted 1p-ISMA\CD with capture

The throughput of Slotted 1p-ISMA\CD with capture is (see section 3.3.2)

$$S = \frac{U(d)}{B(d) + \frac{d}{1-\exp(-dG)}} \sum_{n=1}^{N} R_n[1 - F_{z_n}(z_0)]. \tag{4.17}$$

4.2 Throughput analysis with Rician channel with n-interferers

From different investigations, [16, 12, 8], it is known that in the presence of line of sight paths the multipath fading characteristics are Rician distributed. In a small cellular and indoor environment we have this situation, [11]. In this section, effects of Rice + n Rice on throughput is shown.

4.2.1 Slotted np-ISMA with Rice + n Rice

The test signal is Rice with n-Rice interfering signals. The cell has been described in chapter 2 (figure 2.1). There is a base station (BS) in the middle of each room, which has been considered as one cell, and one desired terminal (T) and n-interfering terminals (i) (from the test cell and the surrounding cells as well) with inhibit delay fraction (d) as 0.001.
The p.d.f. of the instantaneous power of the test packet is :

$$f(P_s) = \frac{1}{\sigma^2}\exp\left[-\frac{2P_s + S^2}{2\sigma^2}\right] I_0\left[\frac{\sqrt{2P_s}S}{\sigma^2}\right] \tag{4.18}$$

with $P_s = \frac{1}{2}A^2$.
According to [7], the sum of n-Rician independent signals is :

$$P_n = \sum_{i=1}^{n} p_i^2 \tag{4.19}$$

The p.d.f. of the sum is

$$f_{P_n}(p_n) = \frac{1}{2\sigma^2}\left[\frac{p_n}{P}\right]^{\frac{n-1}{2}} \exp\left[-\frac{p_n + P}{2\sigma^2}\right] I_{n-1}\left[\frac{\sqrt{Pp_n}}{\sigma^2}\right] \quad \text{where } 0 \le P_n < \infty \tag{4.20}$$

with $P = \sigma^2 \sum_{i=1}^{N1} S_i^2$

But the expression above for P is not correct, if only for dimensional reasons. To find the p.d.f. of the sum of $N1$ signals, the characteristic function of the Rician p.d.f. has to be found. By definition the characteristic function of a p.d.f. is the Fourier transform of this p.d.f.. After multiplying the characteristic function $N1$ times and then calculating the inverse Fourier transform :

$$P = \sum_{i=1}^{N1} S_i^2 \tag{4.21}$$

Using the equations the distribution function is :

$$\begin{aligned} F_{z_n}(z_0) &= \int_0^{z_0} dz \int_0^{\infty} \frac{1}{\sigma^2} \exp[-\frac{2zw + S^2}{2\sigma^2}] I_0[\frac{\sqrt{2zw}S}{\sigma^2}] \cdot \\ & \frac{1}{2\sigma^2}[\frac{w}{P}]^{\frac{n-1}{2}} \exp[-\frac{w+P}{2\sigma^2}] I_{n-1}[\frac{\sqrt{Pw}}{\sigma^2}] w dw \end{aligned} \tag{4.22}$$

By using the transformation

$$\text{parameters} : \begin{aligned} t &= \frac{\sqrt{(2zw)}}{\sigma} \text{ and } \alpha &= \frac{S}{\sigma} \\ x &= \frac{\sqrt{w}}{\sigma} \text{ and } \epsilon &= \sqrt{\frac{P}{\sigma}} \end{aligned}$$

we get

$$F_{z_n}(z_0) = \int_0^{\sqrt{2z_0x}} t \exp[-\frac{t^2+\alpha^2}{2}] I_0[\alpha t] dt \int_0^{\infty} x[\frac{x}{\epsilon}]^{n-1} \exp[-\frac{x^2+\epsilon^2}{2}] I_{n-1}[\epsilon x] dx \tag{4.23}$$

The first integral is a Marcum's Q-function. Thus

$$\begin{aligned} F_{z_n}(z_0) &= [1 - Q(\alpha, \sqrt{2z_0x})] \int_0^{\infty} x[\frac{x}{\epsilon}]^{n-1} \exp[-\frac{x^2+\epsilon^2}{2}] I_{n-1}[\epsilon x] dx \\ &= \int_0^{\infty} x[\frac{x}{\epsilon}]^{n-1} \exp[-\frac{x^2+\epsilon^2}{2}] I_{n-1}[\epsilon x] dx - \\ & \int_0^{\infty} x[\frac{x}{\epsilon}]^{n-1} \exp[-\frac{x^2+\epsilon}{2}] I_{n-1}[\epsilon x] Q(\alpha, \sqrt{2z_0x}) dx \end{aligned} \tag{4.24}$$

The first integral is equal to 1, and the second one can be integrated numerically. Before that is done, the equation can be written as follows:

$$F_{z_n}(z_0) = 1 - \frac{1}{\epsilon^{n-1}} \int_0^{\infty} x^m [\frac{x}{\epsilon}]^{n-1} \exp[-\frac{x^2}{2}] I_{n-1}[\epsilon x] Q(\alpha, \sqrt{2z_0x}) dx \tag{4.25}$$

using the relation

$$S = \frac{dG \exp(-dG)}{1 + d - \exp(-dG)} \sum_{n=1}^{N} R_n[1 - F_{z_n}(z_0)] \tag{4.26}$$

For the calculation, different values of Rice-factor [6] and capture ratio have been used. It is assumed that all interfering signals have the same average fading power, so $\sigma_i^2 = \sigma_2$. The Rician test signal have also the same σ_2. Thus we neglect the near-far effects. All interfering signals are identical, thus P can be written as follows:

$$\begin{aligned} P &= nS^2 \\ &= n2\sigma^2 K \end{aligned} \tag{4.27}$$

and

$$\begin{aligned} \epsilon &= \sqrt{\frac{P}{\sigma}} \\ &= \sqrt{(2nK)} \end{aligned} \tag{4.28}$$

This is due to the assumption that Rice-factor of desired signal and undesired signals are same.

For next following simulations, Rice factor of desired signal and undesired signals are assumed to be having different values.

K_d = desired Rice factor,
K_u = undesired Rice factor,
z_0 = capture ratio.

In figure 4.1, K_d is higher than K_u and by increasing z_0, the throughput decreases with $d = 0.001$. If z_0 has fixed value and vaules of K_u and K_u are similar and increases, figure 4.2, the throughput again decreases. In figure 4.3, When the values of K_d increases, the throughput increases.
Thus concluding that the sum of interfering signals have more influence as the Rice-factor increases.

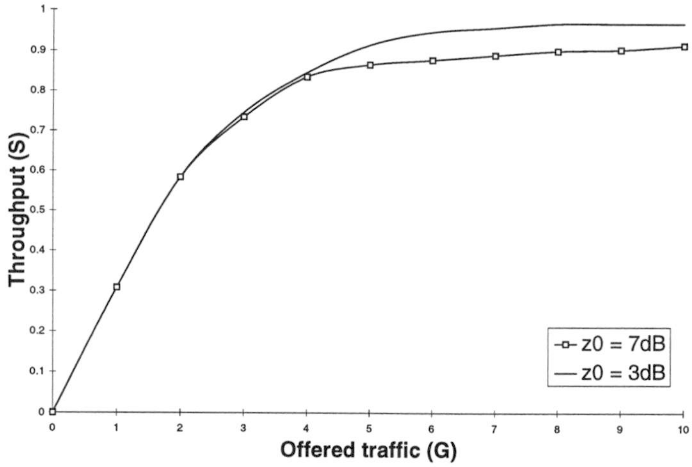

Figure 4.1: Slotted np-ISMA with $z_0 = 3,7dB$, $k_d = 7dB$, $K_u = 3dB$ and $d = 0.001$

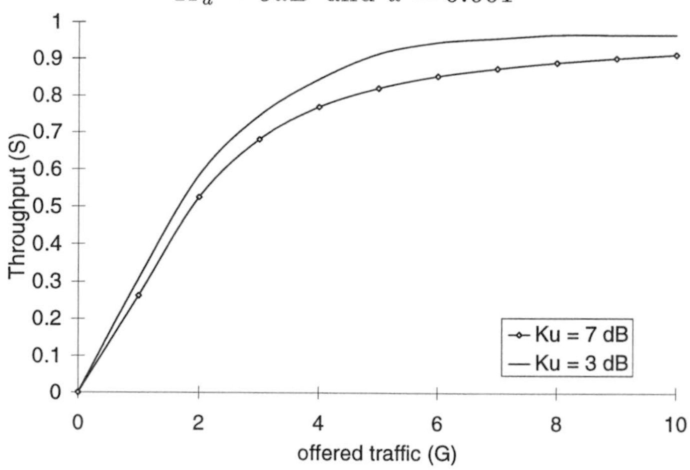

Figure 4.2: Slotted np-ISMA with $z_0 = 3dB$, $K_d = K_u = 7,3dB$ and $d = 0.001$

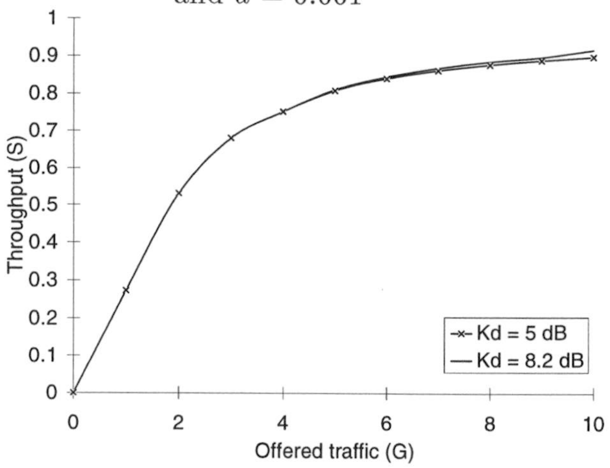

Figure 4.3: Slotted np-ISMA with $z_0 = 3dB$, $K_d = 5,8.2dB$, $K_u = 3dB$ and $d = 0.001$

4.2.2 Slotted 1p-ISMA with Rice + n-Rice

The expression for the throughput is given here again:

$$S = \frac{G\exp(-(1+d)G)(1+d-\exp(-dG)}{(1+d)(1-\exp(-dG))+d\exp(-(1+d)G)}\sum_{n=1}^{N} R_n[1-F_{z_n}(z_0)]. \quad (4.29)$$

Figure 4.4 shows a decreasing throughput with increasing z_0 for fixed values of K_d, K_u and d. With $z_0 = 3dB$ and $d = 0.001$ and increasing $K_d = K_u$, the throughput is decreasing (see figure 4.5). Finally, in figure 4.6, as the K_d increases throughput increases too.

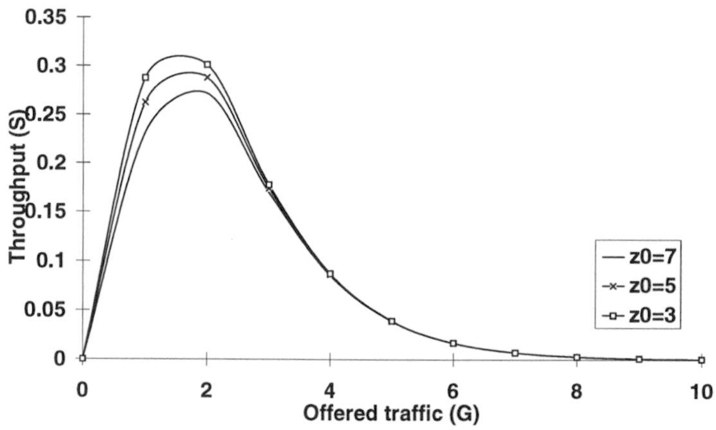

Figure 4.4: Slotted 1p-ISMA with $z_0 = 3, 5, 7dB$, $K_d = 8.2dB$, $K_u = 0dB$ and $d = 0.001$

4.2.3 Slotted np-ISMA\CD with Rice + n-Rice

After manipulating with equations from the previous chapter for this protocol, the computable expression for the throughput is

$$S = \frac{U}{B+I} = \frac{dG\exp(-dG)}{dG\exp(-dG)+(1-\exp(-dG)-dG\exp(-dG))\gamma+d}\cdot \sum_{n=1}^{N} R_n[1-F_{z_n}(z_0)]. \quad (4.30)$$

In figure 4.7, the influence of γ has been shown on the throughput with $z_0 = 3dB$, $K_d = 8.2dB$, $K_u = 0dB$, $d = 0.001$. With higher values of γ

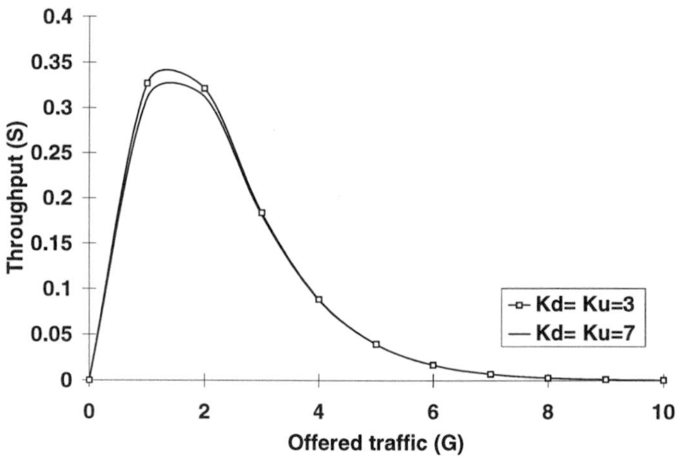

Figure 4.5: Slotted 1p-ISMA with $z_0 = 3dB$, $K_d = K_u = 7, 3dB$ and $d = 0.001$

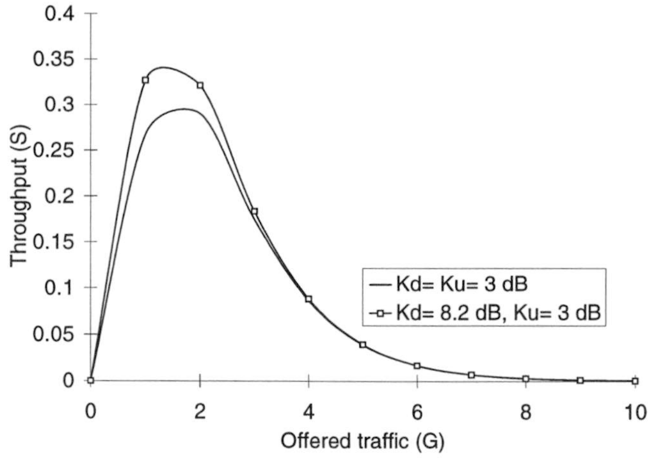

Figure 4.6: Slotted 1p-ISMA with $z_0 = 3dB$, $K_d = 8.2, 3dB$ $K_u = 3dB$ and $d = 0.001$

the throughput decreases. If the z_0 increases with fixed values of K_d, K_u and d, the throughput decreases (see figure 4.8). With increasing K_u, the throughput decreases in figure 4.9. An inverse situation is happening in figure 4.10, with $z_0 = 3dB$, $K_d = 5, 8.2dB$, $K_u = 3dB$, $d = 0.001$ and $\gamma = 0.01$, the throughput increases with the increasing K_d.

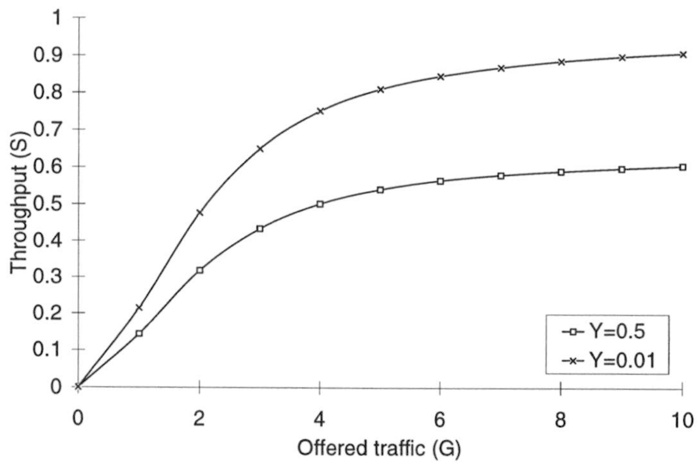

Figure 4.7: Slotted np- ISMA\CD with $z_0 = 3dB$, $K_d = 8.2dB$, $K_u = 0dB$, $d = 0.001$ and $\gamma = 0.5, 0.01$

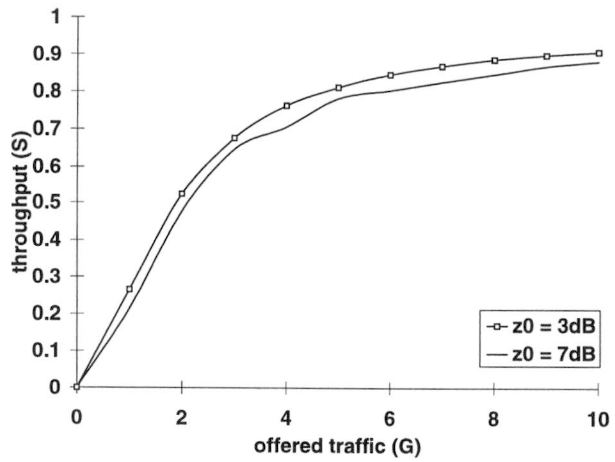

Figure 4.8: Slotted np- ISMA\CD with $z_0 = 3, 7dB$, $K_d = 8.2dB$, $K_u = 0dB$, $d = 0.001$ and $\gamma = 0.01$

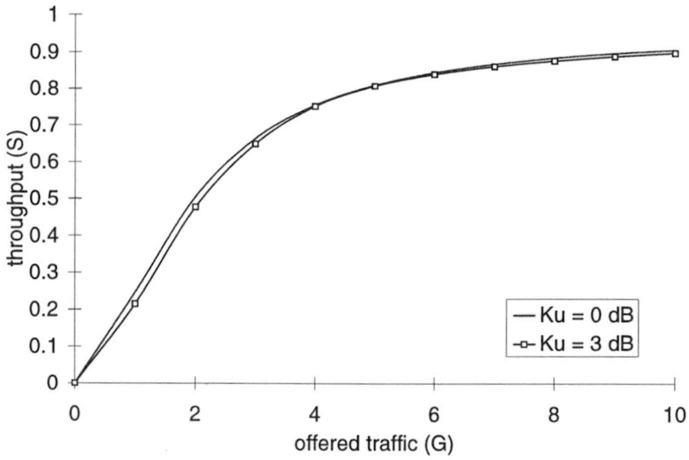

Figure 4.9: Slotted np- ISMA\CD with $z_0 = 3dB$, $K_d = 8.2dB$, $K_u = 0, 3dB$, $d = 0.001$ and $\gamma = 0.01$

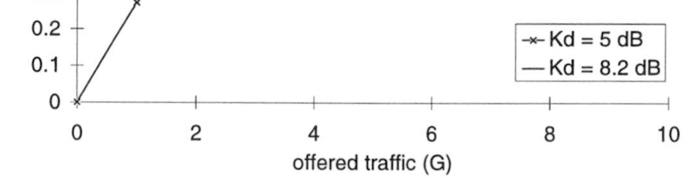

Figure 4.10: Slotted np- ISMA\CD with $z_0 = 3dB$, $K_d = 5, 8.2dB$, $K_u = 3dB$, $d = 0.001$ and $\gamma = 0.01$

5. Comparison of the ISMA protocols

Using the results for Slotted np-ISMA, Slotted 1p-ISMA and Slotted np-ISMA\CD from the previous chapter, a comparison has been made between these protocols.
In the situation for Rice + n-Rice the performances between Slotted np-ISMA and Slotted np-ISMA\CD are similar for less users, but Slotted np-ISMA\CD depends on the values of γ (see figure 5.2). This protocol performs better when more mobile users ($G \geq 10$) are present (see figure 5.1). The values of K_d and K_u are taken from [6] which have been calculated for a real environment.

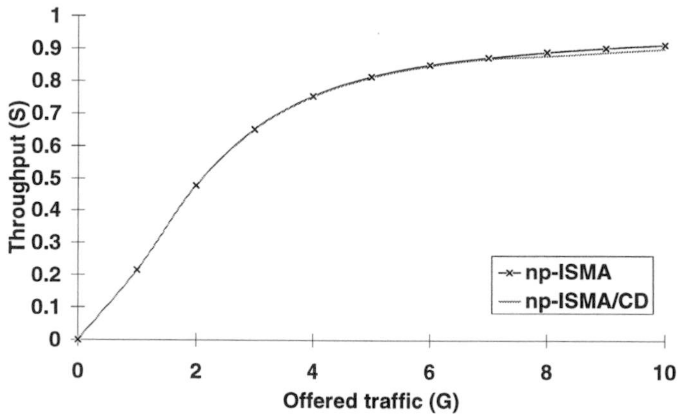

Figure 5.1: Slotted np-ISMA versus Slotted np-ISMA\CD with $z_0 = 3$, $K_d = 8.2$, $K_u = 0$, $d = 0.001$ and $\gamma = 0.01$

From figure 5.3, it shows that at lower traffic ($G \leq 2$) Slotted 1p-ISMA performs better than Slotted np-ISMA and Slotted np-ISMA\CD. But, Slotted np-ISMA and Slotted np-ISMA\CD gives much better performance for $G \geq 2$ while that of Slotted 1p-ISMA approches to zero.

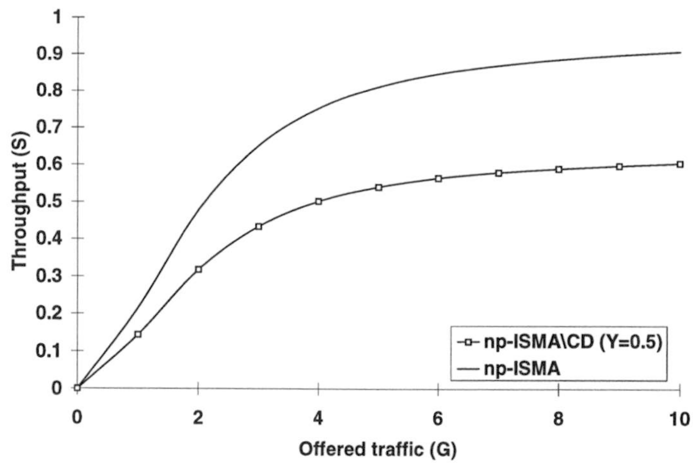

Figure 5.2: Comparison between Slotted np-ISMA and Slotted np-ISMA\CD with $z_0 = 3$, $K_d = 8.2$, $K_u = 0$, $d = 0.001$ and $\gamma = 0.5$

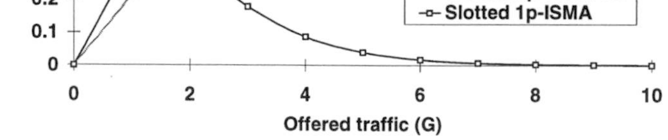

Figure 5.3: Comparison between Slotted np-ISMA, Slotted 1p-ISMA and Slotted np-ISMA\CD for $z_0 = 3$, $K_d = 8.2$, $K_u = 0$, $d = 0.001$ and $\gamma = 0.5$

6. Conclusions and Recommendations

Conclusions

Throughput is derived and evaluated for Slotted np-ISMA, Slotted 1p-ISMA and Slotted np-ISMA\CD. From the computational results obtained in this investigation, the following conclusions are drawn.

A : Slotted np-ISMA

1. When desired and undesired Rice factor are identical, for a fixed z_0 and $d = 0.001$ as the Rice factor increases the throughput decreases. This occurs because the summation of the interferers have more influence.
2. With the Rice-factors identical and z_0 increasing, the results are worse.
3. In the case of $K_u > K_d$ and fixed K_d and z_0, the throughput gets lower by higher values of K_u.
4. For the case of where $K_d > K_u$ with fixed K_u and z_0 and increasing K_d, the performance is better.

B : Slotted 1p-ISMA

1. Conclusions for Slotted 1p-ISMA are similar to those for Slotted np-ISMA.
2. However, it shows worse performance.

C : Slotted np-ISMA\CD

1. The throughput decreases as the γ value increases.
2. It has similar results for low traffic but gives better performance when the traffic is higher for lower values of γ.
3. Further, the conclusions for Slotted np-ISMA\CD are similar to those for Slotted np-ISMA.

D : Comparison between the protocols

1. At lower values of γ performance of Slotted np-ISMA and Slotted np-ISMA\CD are similar and better than Slotted 1p-ISMA.

2. With higher values of γ Slotted np-ISMA gives the best performance.

E : Remarks

Thus Slotted np-ISMA is recommended for Pico Cellular Systems for lower offered traffic ($G < 11$).

Recommendations

1. Performance of Slotted 1p-ISMA\CD should be evaluated and compared with Slotted np-ISMA, Slotted 1p-ISMA and Slotted np-ISMA\CD.

2. The performance of all the four protocols should be investigated for higher offered traffic.

3. Performance of the ISMA protocols should be also investigated for shadowed Rician indoor faded environment

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Appendices

A. Throughput of Slotted 1-persistent ISMA\CD

As given in section 3.3.2, busy period as the function of x is denoted as $B(x)$. Given that a transmission period is of lenght x, the average time the channel is carrying successful transmissions in remainder of the busy period is denoted as by $U(x)$.
The quantity $B(x)$ is given by

$$\begin{aligned} B(x) &= \frac{a_1(x)}{1-a_0(x)}\left[T+\tau+\left[1-a_0(T+\tau)\right]B(T+\tau)\right]+ \\ & \left[1-\frac{a_1(x)}{1-a_0(x)}\right]\left[\lambda+\tau+\left[1-a_0(\lambda+\tau)\right]B(\lambda+\tau)\right] \quad \text{(A.1)} \end{aligned}$$

Let $a_i(x)$ be the probability of i arrivals during a period of length x. Under the Poisson assumption

$$a_i(x) = (gx)^i \frac{e^{(gx)}}{i!}$$

The first term in equation (A.1) corresponds to a successful transmission of single packet that arrives during x, in which case the remainder of the busy period will be of length $T+\tau$ (the length of a successful transmission period). In addition, if there is at least one arrival within $T+\tau$ (probability $1-a_0(T+\tau)$), the remainder of the busy period is of length $B(T+\tau)$. The second term in equation (A.1) corresponds to an unsuccessful transmission due to the arrivals during x, in which case the remainder of teh busy period will be of length $\gamma+\tau$ (the length of an unsuccessful transmission period) (see figure 3.8).
The expected duration of the entire busy period is $B(\tau)$ since x, the argument of $B(.)$ can be interpreted as an arrival period for the next transmission period and clearly the arrival period for the entire busy period in the first slot before started. Oberserving equation (A.1) we notice that substituting τ for x in equation (A.1) is not quite enough since values of $B(.)$ appear on the right handside as well. This can be overcome by assuming

$$
\begin{aligned}
\alpha(x) &= \frac{a_1(x)}{1-a_0(x)} \\
\beta &= [1-a_0(T+\tau)] \\
\vartheta &= [1-a_0(\lambda+\tau)]
\end{aligned}
$$

Thus,

$$B(x)=\alpha(x)\left[T+\tau+\beta B(T+\tau)\right]+\left[1-\alpha(x)\right]\left[\lambda+\tau+\vartheta B(\lambda+\tau)\right] \quad \text{(A.2)}$$

Let $m=T+\tau$ and $n=\lambda+\tau$ then if $x=m$ (A.2) becomes:

$$B(m)=\alpha(m)\left[m+\beta\alpha(m)\right]+\left[1-\alpha(m)\right]\left[n+\vartheta B(n)\right] \quad \text{(A.3)}$$

Combining terms gives:

$$B(m) = \frac{\alpha(m)m-\left[1-\alpha(m)\right]\left[n+\vartheta B(n)\right]}{1-\alpha(m)\beta} \quad \text{(A.4)}$$

$$B(n) = \frac{B(m)\left[1-\alpha(m)\beta\right]-\alpha(m)m-\left[1-\alpha(m)\right]n}{\vartheta\left[1-\alpha(m)\right]} \quad \text{(A.5)}$$

Substituting $x=n$ in (A.2),

$$B(n)=\alpha(n)\left[n+\beta B(n)\right]+\left[1-\alpha(n)\right]\left[n+\vartheta B(n)\right] \quad \text{(A.6)}$$

Again combining terms:

$$B(m) = \frac{-\alpha(m)m-\left[1-\alpha(n)\right]n+\left[1-\vartheta\left[1-\alpha(n)\right]\right]B(n)}{\alpha(n)\beta} \quad \text{(A.7)}$$

$$B(n) = \frac{\alpha(n)\left[m+\beta B(m)\right]+\left[1-\alpha(n)\right]n}{1-\left[1-\alpha(n)\right]\vartheta} \quad \text{(A.8)}$$

Subtracting (A.7) from (A.4) gives

$$B(n)=\frac{\left\{\alpha(m)m+\left[1-\alpha(n)\right]n\right\}\alpha(n)\beta+\left\{\alpha(n)m+\left[1-\alpha(n)\right]n\right\}\left\{1-\alpha(m)\beta\right\}}{\left\{1-\vartheta\left[1-\alpha(n)\right]\right\}\left[1-\alpha(m)\beta\right]-\left[1-\alpha(m)\right]\vartheta\alpha(m)\beta} \quad \text{(A.9)}$$

Subtracting (A.5) from (A.8) gives

$$B(m)=\frac{\left\{\alpha(n)m+\left[1-\alpha(n)\right]n\right\}+\left\{\alpha(m)m+\left[1-\alpha(m)\right]n\right\}\left\{1-\left[1-\alpha(m)\right]\vartheta\right\}}{\left\{\beta\alpha(n)\vartheta\left[1-\alpha(m)\right]\right\}-\left[1-\alpha(m)\beta\right]-\left\{\left[1-\alpha(m)\beta\right]\left[1-\left[1-\alpha(n)\right]\vartheta\right]\right\}} \quad \text{(A.10)}$$

Substituting $\alpha(.), n, m, \beta, \vartheta$ and $a_i(.)$ in (A.9) and (A.10) gives

$$
\begin{aligned}
B(n) = {} & \frac{\left\{\frac{g(T+\tau)}{e^{g(T+\tau)}-1}(T+\tau)+\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}(\lambda+\tau)\right]\right\}\frac{g(\lambda+\tau)\left[e^{g(\lambda+\tau)}-1\right]}{e^{g(T+\tau)}e^{g(\lambda+\tau)}}}{\left\{1-\frac{\left[e^{g(\lambda+\tau)}-1\right]}{e^{g(\lambda+\tau)}}\left[1-\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\right]\right\}\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right]-\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right]\frac{e^{g(\lambda+\tau)}-1}{e^{g(\lambda+\tau)}}\frac{g(T+\tau)}{e^{g(T+\tau)}-1}} \\
& + \frac{\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}(T+\tau)+\left[1-\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\right](\lambda+\tau)\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right]}{\left\{1-\frac{\left[e^{g(\lambda+\tau)}-1\right]}{e^{g(\lambda+\tau)}}\left[1-\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\right]\right\}\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right]-\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right]\frac{e^{g(\lambda+\tau)}-1}{e^{g(\lambda+\tau)}}\frac{g(T+\tau)}{e^{g(T+\tau)}-1}}
\end{aligned}
\quad \text{(A.11)}
$$

$$B(m) = \frac{\left\{\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}(T+\tau)+\left[1-\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\right](\lambda+\tau)\right\}\frac{g(T+\tau)}{e^{g(T+\tau)}-1}(T+\tau)}{\left[e^{g(\lambda+\tau)}-1\right]\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\left[e^{g(T+\tau)}-1\right]\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right]-\left\{1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\left[e^{g(T+\tau)}-1\right]\right\}\frac{[g(\lambda+\tau)-1]e^{g(\lambda+\tau)}+1}{e^{g(\lambda+\tau)}-1}}$$

$$+ \frac{\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right](\lambda+\tau)\left\{1-\left[1-\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\right]\left[e^{g(\lambda+\tau)}-1\right]\right\}}{\left[e^{g(\lambda+\tau)}-1\right]\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\left[e^{g(T+\tau)}-1\right]\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right]-\left\{1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\left[e^{g(T+\tau)}-1\right]\right\}\frac{[g(\lambda+\tau)-1]e^{g(\lambda+\tau)}+1}{e^{g(\lambda+\tau)}-1}} \tag{A.12}$$

Thus $B(T+\tau)$ and $B(\lambda+\tau)$ are known, finally substituting (A.11) and (A.12) in (A.1) gives $B(x=\tau)$ directly as a function of τ, given T, λ and g.
In a similar manner, $U(x)$ is given by

$$U(x) = \alpha(x)\left[T+\beta U(m)\right] + \left[1-\alpha(x)\right]\vartheta U(n) \tag{A.13}$$

Substituting $x = m$ in (A.13) gives

$$U(n) = \alpha(n)\left[T+\beta U(m)\right] + \left[1-\alpha(n)\right]\vartheta U(n) \tag{A.14}$$

Thus

$$U(m) = \left\{1-\left[1-\alpha(n)\right]\vartheta\right\}U(n) - \alpha(n)T\alpha(n)\beta \tag{A.15}$$

$$U(n) = \frac{\alpha(n)\left[T+\beta U(m)\right]}{\left[1-\alpha(m)\beta\right]} \tag{A.16}$$

Subtracting (A.16) from (A.13) gives

$$U(m) = \frac{-\alpha(m)T\left\{1-\left[1-\alpha(n)\right]\vartheta\right\} - \alpha(n)T\left[1-\alpha(m)\right]\vartheta}{\alpha(n)\beta\left[1-\alpha(m)\right]\vartheta - \left[1-\alpha(m)\beta\right]\left\{1-\left[1-\alpha(n)\right]\vartheta\right\}} \tag{A.17}$$

Similarly subtracting (A.15) from (A.12)

$$U(n) = \frac{\alpha(m)\alpha(n)\beta + \alpha(n)T\left[1-\beta\alpha(m)\right]}{\left\{1-\left[1-\alpha(n)\right]\vartheta\right\}\left[1-\alpha(m)\beta\right] - \left[1-\alpha(m)\right]\vartheta\alpha(n)\beta} \tag{A.18}$$

Substituting $\alpha(.), n, m, \beta, \vartheta$ and $a_i(.)$ in (A.17) and (A.18)
$U(m) =$

$$\frac{-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}T\left\{1-\left[1-\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\right]\right\}\left[e^{g(T+\tau)}-1\right]}{\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\left[e^{g(T+\tau)}-1\right]\left[1-\frac{g(T+\tau)}{e^{-g(T+\tau)}}\right]\left[e^{g(\lambda+\tau)}-1\right]-\left\{1-\frac{g(T+\tau)}{e^{-g(T+\tau)}}\left[e^{g(T+\tau)}-1\right]\right\}\frac{[g(\lambda+\tau)-1]\left[e^{-g(\lambda+\tau)}+1\right]}{e^{g(\lambda+\tau)}-1}} -$$

$$\frac{\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}T\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right]\left[e^{g(\lambda+\tau)}-1\right]}{\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\left[e^{g(T+\tau)}-1\right]\left[1-\frac{g(T+\tau)}{e^{-g(T+\tau)}}\right]\left[e^{g(\lambda+\tau)}-1\right]-\left\{1-\frac{g(T+\tau)}{e^{-g(T+\tau)}}\left[e^{g(T+\tau)}-1\right]\right\}\frac{[g(\lambda+\tau)-1]\left[e^{-g(\lambda+\tau)}+1\right]}{e^{g(\lambda+\tau)}-1}} \tag{A.19}$$

$U(n) =$

$$\frac{\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\left[e^{g(T+\tau)}-1\right]+\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}T\frac{[g(\lambda+\tau)-1]\left[e^{-g(\lambda+\tau)}+1\right]}{e^{g(\lambda+\tau)}-1}}{\left[g(\lambda+\tau)+1\right]-\frac{1+g(\lambda+\tau)-e^{-g(\lambda+\tau)}}{e^{g(\lambda+\tau)}}\left\{1-\frac{\left[1-e^{-g(\lambda+\tau)}\right]g(\lambda+\tau)}{e^{g(\lambda+\tau)}-e^{-g(\lambda+\tau)}}\right\}-\left[1-\frac{g(T+\tau)}{e^{g(T+\tau)}-1}\right]\left[e^{g(\lambda+\tau)}-1\right]\frac{g(\lambda+\tau)}{e^{g(\lambda+\tau)}-1}\left[e^{g(T+\tau)}-1\right]} \tag{A.20}$$

Now having $U(T+\tau)$ and $U(\lambda+\tau)$, $U(x=\tau)$ from (A.13) can be written directly as a function of τ, given T, λ and g.

Now knowing $B(\tau)$ and $U(\tau)$, (given T, λ and g) with an average length of an idle period is $\tau/(1-\exp -g\tau)$, the threshold can be given by

$$S = \frac{U}{B+I} = \frac{U(\tau)}{B(\tau) + \frac{\tau}{1-e^{-g\tau}}} \tag{A.21}$$

APPENDIX B

Slotted ALOHA and Unslotted Non-persistent ISMA for Indoor Pico Cellular Communication

Neeli R. Prasad, Student Member, IEEE
Jos Nijhof, Member, IEEE

Telecommunications and Traffic Control Systems group
Delft University of Technology
P.O. Box 5031, 2600 GA Delft
The Netherlands
Fax: +31-15-781774

ABSTRACT

The paper presents the throughput of Slotted ALOHA and unslotted non-persistent ISMA and spectrum efficiency of a single cell data network. These have been analysed using interference model in Rician fading environment and capture effect in a single cell structure. The results maybe of importance for the future Indoor Wireless communications (IWC).

1. Introduction

In the last few years the demand of IWC has grown significantly. This fast growing numbers of users demands efficient use of scarce frequency spectrum. Cellular radio systems has been classified into three categories: i) marcocells of 2 to 20 km diameter, ii) microcells of 0.4 to 2 km and iii) picocells of much smaller size (20 to 400 m) especially suited for indoor radio communications (e.g. offices, research laboratories, hospitals modern factories, university campuses, etc.).

This paper considers the situation where terminals communicating with a centrally located base station using packet radio. During this communication, terminals compete with each other to get access to the common channel, thus giving a reason to investigate, which multiple access protocols are suited for this required situation. Two protocols have been investigated for the performance in pico cellular systems for a single cell structure.

The rooms of 19th and 20th floors of Electrical Engineering, Delft University of Technology, The Netherlands, has been considered for this investigation [1]. The rooms are located on the both sides of 65 m long and 2 m wide, straight corridor. Each room is 4 m wide, 6 m long and 2.80 m high. These rooms are separated by a wall made of plaster board, rockwool and steel frames. The separating wall of corridor and rooms is made of bricks. The floor is made of inforced concrete of 50 cm and above the doors of each room, at the height of 2.10 m, a glass window runs up to the ceiling. There is an open stairway on the both end of the corridor leading to the upper and lower floors. Each room has been considered a cell, with a centrally located base station using packet radio.

The investigation includes the channel where the test terminal and the interfering terminals are within a small cell, so the signals coming from both the test terminal and the interfering terminals are Rician distributed. Spectrum efficiency has also been looked into.

2. Indoor Wireless Communication Channel

The terminals are assumed to be in one room of the 19th or 20th floor with base station in the centre. In this way, the amplitude of the signals can be modelled by Rician pdf (probability density function) [1]

$$f(A) = \frac{A}{\sigma^2} exp(-\frac{A^2 + s^2}{2\sigma^2}) I_0(\frac{As}{\sigma^2}) \quad (1)$$

where A is the signal amplitude, σ^2 is the average fading power, s is the peak amplitude of the dominant received multipath component and $I_n(\cdot)$ is the modified Bessel function of the first kind and n^{th} order. From (1) the pdf of the fast varying instantaneous power, $p = \frac{A^2}{2}$, is found as

$$f(p) = \frac{K+1}{p_0} exp\left(-\frac{K+1}{p_0} p - K\right) \times I_0\left(2\sqrt{\frac{K^2+K}{p_0} p}\right) \quad (2)$$

where $p_0 = \frac{s^2 + 2\sigma^2}{2}$ is the local mean power and K the Rician factor , which is defined as the ratio of the average power of the dominant multipath component and the average fading power receiver over the non-dominant paths

$$K = \frac{s^2}{2 * \sigma^2} \quad (3)$$

3. Performance Analysis

The protocol performance has been measured in terms of throughput S in relationship with the offered traffic G. The efficiency of the protocol can be measured by the throughput and is defined as the fraction of time in which correct data packets are received.

3.1 Slotted ALOHA

All active terminals are assumed to transmit their messages to a single receiver over a common channel in packets of duration τ, regardless of the results of the competing terminals. An unsuccessful packet will be retransmitted after waiting a random number of slots. The channel is memoryless, i.e., a retransmitted packet experiences collisions uncorrelated with its previous attempts to capture the receiver [2].
If the number of packets generated in the network (for messages plus retransmissions) are binomial distributed, with mean generation rate λ packets per second, the mean offered channel traffic expressed in packets per time is

$$G = \lambda * \tau \quad (4)$$

The probability of a test signal being overlapped by n other packets is then

$$Pr[n] = \binom{N}{n}\left[\frac{G}{N}\right]^n \left[1 - \frac{G}{N}\right]^{N-n} \quad (5)$$

where G is the offered traffic as the average number of transmissions per time slot, n is the active number of users and N is maximum number of users in a cell. With capture effect

$$P_{cap}(z_0) = 1 - \sum_{n=1}^{N} Pr[n]\, Prob\{P_s / P_n < z_0\} \quad (6)$$

The channel throughput S is given [2] by

$$S = G\left[1 - \sum_{n=1}^{N} Pr[n] F_{zn}(z_0)\right] \quad (7)$$

with

$$F_{zn}(z_0) = \int_0^{z_0} dz \int_0^{\infty} f_{ps}(zw) f_{pnr}(w)\, w\, dw \quad (8)$$

as distribution function to calculate the throughput in the presence of Rician interfering signals.

3.2 Unslotted Non-persistent ISMA

In Unslotted np-ISMA, the transmission only occurs when the terminal gets permission to transmit, i.e., if an idle signal is received on the signalling channel. If there is a busy signal, the transmission attempt will be unsuccessful. Such packets are rescheduled for later by putting them into retransmitting buffer. We assume that the arrivals of these packets are generated by a binomial
process.
The throughput is given by using eq.(5) and (6)

$$S = \frac{exp(-dG) + \sum_{n=1}^{N} \frac{(n+1)}{\varepsilon^{n-1}} P_r[n]\, exp\left[-\frac{\varepsilon^2}{2}\right] \int_0^{\infty} x^m\, exp\left[-\frac{x^2}{2}\right] I_{n-1}[\varepsilon x]\, Q\left(\alpha, \sqrt{2z_0}\, x\right) dx}{1 + 2d + \frac{1}{G} exp(-dG)} \quad (9)$$

where d is the inhibit delay fraction [3,4].

4. Spectrum Efficiency

This section describes the indoor wireless data network structure for the 19th floor of the Electrical Engineering Department of the Delft University of Technology by evaluating the spectrum efficiency.

We know from [1] that the maximum failure probability for the 19th floor network is 1.46%. Therefore the capture probability can be obtained by

$$P_{cap}(z_0) = 1 - P_{fail}(z_0) \quad (10)$$

So, $P_{cap}(z_0) = 98.54\%$ from eq. (10). Any network should provide the maximum channel capacity and the highest spectrum efficiency. We know from eq. (7) and (9) that the throughput is maximal for the maximum success probability. Therefore for the both protocols, $p_{cap}(z_0) = 98.54\%$, provides the maximum throughput.

Spectrum efficiency can be obtained by [6]

$$SE = \gamma \frac{P_{cap}(z_0)}{sC_u} \cdot \frac{L-H}{L} \quad \left[\frac{bits}{sMHz - km^2}\right] \quad (11)$$

where the modulation speed γ represents the bit rate (R_b) to bandwidth (B_T) ratio, $\gamma = \frac{R_b}{B_T}$ with $B_T = W$, s is the cell area, L is the packet length and H is the length of the header. The number of user data bits per packet is L-H. The $P_{cap}(z_0)$ depends on certain values of the receiver threshold. Different values of threshold corresponds to a certain type of modulation. For example, with modulation type FSK $\left(f_b = \frac{R_b}{2}\right)$ and DPSK (M=8), γ amounts to 1 and 3 respectively.

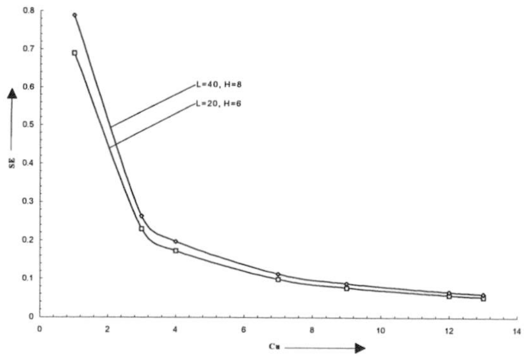

Figure 2 : Spectrum Efficiency SE versus cluster size C_u for $\gamma = 1$ and $s = 1\ km^2$

Fig. 2 shows the plot of spectrum efficiency versus cluster size (Cu) and reuse distance (R_u). Cluster size and reuse distance are related as [5]

$$R_u = \sqrt{3C_u} \quad (12)$$

the cluster size is given by [5]

$$C_u = i^2 + ij + j^2, \quad i, j \geq 0 \quad (13)$$

with integer i and j. Eq.(13) gives $C_u = 1, 3, 4, 7, 9, 12, 13.....$

It can also be seen from fig. 2 that the spectrum efficiency is maximum for $C_u = 1$ and minimum reuse distance.

Fig. 3 shows the plot for spectrum efficiency versus packet length (*L*) for header length (*H*) as a parameter

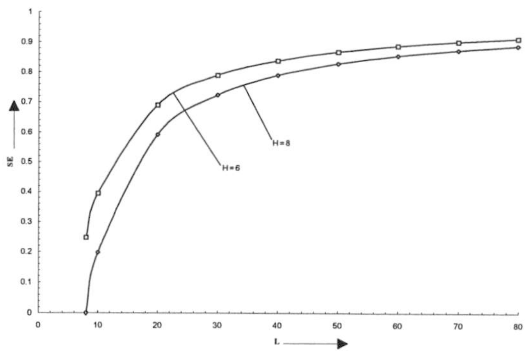

Figure 3: Spectrum efficiency SE versus packet packet length *L* for *H*=6 and 8 bytes in case of $C_u = 1$, $\gamma = 1$ and $s = 1\ km^2$

Thus we know that at maximum spectrum efficiency highest throughput can be obtained for unit cluster size.

4. Conclusions

The throughput of the Slotted ALOHA and Unslotted Non-persistent ISMA, protocols have been analysed by considering a Rician distribution with capture effect.
Further study has been done to spectrum efficiency for indoor wireless data network structure for 19th floor.
When comparing spectrum efficiency of packet length of 20 and 40 bytes with header length 6 and 8 bytes respectively, the latter system offers higher maximum spectrum efficiency at cluster size 1, thus giving the highest throughput.
The present study will be extend by developing a model to Rician fading interfering signals and influence of multiple cell for indoor wireless communications, taking into consideration protocols like Unslotted ALOHA, Unslotted Non-persistent ISMA, Slotted Non-persistent ISMA and p-persistent ISMA.

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Appendix C

Indoor Wireless Communication using Slotted Non-persisntet ISMA, 1-persistent ISMA and Non-persistent ISMA\CD

N. R. Prasad and J. A. M. Nijhof
Telecommunication and Traffic-Control Systems Group
Department of Electrical Engineering
Delft University of Technology
P.O. 5031, 2600 GA Delft
The Netherlands

1 Summary

The significance of the Information Age for communications networks is not so much that people will be communicating more with one another, but that we are constructing intelligent systems - factories, hospitals, banks and dozens of other intelligent economic modules - that will consume and generate information on a vast scale.
The Information Age traffic will be increasingly:

1. Heterogeneous in terms of the original form of the message, mixing modes (data, voice, video), bandwidth, and other characteristics in a common traffic stream
2. subject to stringent error control to provide guaranteed quality of transmitted information
3. Rapidly evolving in format as the applications environment undergoes continuous technology change
4. Demanding of flexible bandwidth
5. Semi-real-time and non-real-time communications will become much more important
6. Requiring high reliability and redundancy.

To be able to support the new systems, the orientation toward circuit-like communications, and requirement for efficient spectrum utilisation, we are mainly interested in what are called multiple-access architectures. Multiple-access systems are designed to allow a large number of users to share a common pool of radio-telephone circuits, much like the sharing of any other common or trunked network facility.
Wireless systems are bringing some new problems along. One of these faced today is that numerous users that share the same communication channel cause conflicts, if several users want to transmit at the same time. Unlike the traditional networks, which made use of the point-to-point channels. These channels have non-interference feature, but this requires to be fixed which is not possible for wireless communication. So, to avoid interference in wireless systems there must be some regulation on how the available channel capacity is allocated to the users. These constitute mul-

tiple access protocols, through which users have to follow some rules in order to access the common channel.
A need for multiple access protocol arises when the network is accessed by more than one independent users and thus causing a conflict. Multiple access protocol can avoid or try to resolve these conflicts. To avoid the conflicts, protocol will have to give every user their own resources. But, this may not be possible because of the scarcity or high cost of the resources. Thus multiple access protocol used in the wireless communication systems shares the resources in the channel. In this case the two main reasons to share the resources among the users are:

1. the resources are scarce and/or expensive,
2. a need for a user to be able to communicate with all the other users, e.g. telephone system.

In 1970, the very first multiple access protocol was developed at the university of Hawaii (the ALOHA [1]). Since then many new protocols have been developed, viz. Slotted ALOHA, CSMA, ISMA, PRMA, etc [1, 2, 3, 4, 5, 6, 7].

Inhibit Sense Multiple Access (ISMA) protocol has been investigated by several authors [4, 5, 6, 7].

All the earlier studies have only considered Unslotted and Slotted Non-persistent ISMA. This paper presents first time the performance analysis of Slotted 1-persistent ISMA (1p-ISMA) and Slotted Non-persistent ISMA with Collision Detection (np-ISMA\CD). The throughput has been derived for both protocols in Rician fading channel with capture effect for Indoor Wireless Communications.

For low offered traffic in a Pico cellular system Slotted np-ISMA gives the best performance. Slotted np-ISMA\CD gives the similar results depending on the values of the ratio of time taken by (user's standpoint) one transmission period with collision detection and the transmission time of a packet and Slotted 1p-ISMA gives the worst performance. Based on the analytical and computational results obtained in this investigation, the following conclusions have been drawn.

2 Conclusions

A : Slotted np-ISMA

1. When desired and undesired Rice factor are identical, for a fixed z_0 (capture ratio) and $d = 0.001$ (inhibit delay fraction) as the Rice factor increases the throughput decreases. This occurs because the summation of the interferers have more influence.
2. With the Rice-factors identical and z_0 increasing, the results are worse.
3. In the case of undesired Rice-factor, $K_u > K_d$ and fixed (desired Rice-factor) K_d and z_0, the throughput gets lower by higher values of K_u.
4. For the case of where $K_d > K_u$ with fixed K_u and z_0 and increasing K_d , the performance is better.

B : Slotted 1p-ISMA

1. Conclusions for Slotted 1p-ISMA are similar to those for Slotted np-ISMA.
2. However, it shows worse performance.

C : Slotted np-ISMA\CD

1. The throughput decreases as the γ' (ratio of time taken to complete a successful transmission by the user and successful packet transmission) value increases.

2. It has similar results for low traffic but gives better performance when the tra ffic is higher for lower values of γ'.

3. Further, the conclusions for Slotted np-ISMA\CD are similar to those for Slotted np-ISMA.

D : Comparison between the protocols

1. At lower values of γ' performance of Slotted np-ISMA and Slotted np-ISMA\CD are similar and better than Slotted 1p-ISMA.

2. With higher values of γ' Slotted np-ISMA gives the best performance.

E : Remarks

Thus Slotted np-ISMA is recommended for Pico Cellular Systems for lower offered traffic ($G < 11$).

If the paper is accepted, full analysis of these protocols, namely, Slotted Non-persistent ISMA, Slotted 1-persistent ISMA and Slotted non-persistent ISMA\CD and the performance measure results will be presented in the full paper.

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D. Symbol Definition List

symbol	definition
ISMA	Inhibit Sense Multiple Access
np-ISMA	Non-persistent ISMA
np-ISMA\CD	Non-persistent ISMA with Collison Detection
1p-ISMA	1-persistent ISMA
CDMA	Code Division Multiple Access
PRMA	Packet Reservation Multiple Access
CSMA	Carrier Sense Multiple Access
G	Offered traffic
S	Throughput
B	Expected duration of busy period
d	Inhibit Delay Fraction
I	Expected duration of idle period
I_0	Zero order modified Besselfunction
K_d	Desired Rice factor
K_u	Undesired Rice factor
P	Sum of direct power
P_0	Mean power
P_i	Average recieved interfering power
P_s	Power of desired signal
P_n	Cumulative interfering power
P_{capt}	Propability of being able to capture the reciever
P_{suc}	Probability of success of the test packet
A	signal amplitude
σ^2	average fading power
K	Rice factor
$Q(\alpha, \beta)$	Marcum's Q-function
R_n	Probability that test packet is overlapped by n interfering signals
U	Time during a cycle the the channel is used without conflicts
z_0	Capture ratio
γ	Time taken for a successful tranmission