

AVTR - A Random Access Method for Mobile Networks

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Abstract— This paper describes a novel Adaptive Virtual Token Ring (AVTR) multiple access protocol. The random access method presented is shown to be a spatial derivative of a Token Ring network. The operation of the system is described with reference to its application in cellular networks capable of providing a range of heterogeneous services such as voice and data. Specifically, it is shown how the system can easily be used to perform dynamic Quality of Service (QoS) management with little additional hardware resources required.

I. INTRODUCTION

With the introduction of UMTS imminent [1], mobile communications networks will be used to provide a myriad of heterogeneous services such as voice, data and video, each with its own traffic characteristics and QoS requirements. For instance, real time voice circuits require low throughput delays but can tolerate high Bit Error Ratios (BER) whereas data circuits can tolerate longer throughput delays but require low BER's. Furthermore, these services will all be present in a single cell and will need to compete for available radio resources. It is in this scenario that packet data services are becoming increasingly important to deliver both connectionless and connection oriented services to users. The advantage of a packet data services is that the service can be configured to optimally use available system resources, i.e. when the level of real-time traffic in a network is low large amounts of packet data can be sent [2]. This increased data throughput will clearly lead to an increased system capacity.

In addition to packet data services, mobile radio networks are also making use of adaptive antenna arrays to implement Space Division Multiple Access (SDMA) systems to further increase system capacities. A SDMA system is a multiple access technique which enables two or more users, affiliated to the same base station to use the same time slot, frequency slot or code resources based on their physical location or spatial separation [3], [4]. The key enabling technology for SDMA systems is adaptive antenna arrays which traditionally provides the base station with the capability of steering the radiation pattern of the base station antenna in any direction in order to isolate a single user in the cell and even

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track that particular user.

In addition to the implementation of SDMA systems, adaptive antenna array technology can also be used in conjunction with multiple access methods to control of access to the radio resource, viz. perform Medium Access Control (MAC). Specifically, antenna arrays have been used to “zoom in” on users in a Slotted ALOHA network to increase the throughput of the system [5].

In this paper, a new strategy combining MAC protocols with antenna arrays will be presented. This combination will be shown to yield a system with throughput similar to that of a Token Ring network. In section II, the rationale behind the design of the system is introduced by considering the QoS requirements of a third generation mobile network. Following this, the operation of the AVTR system is described in section III, with some conclusions identifying future research activities presented in section IV.

II. QUALITY OF SERVICE DISTRIBUTION

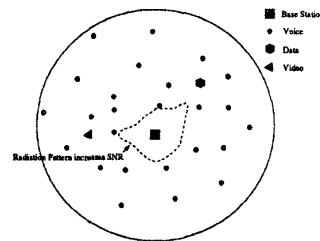


Fig. 1. Quality Of Service Inhomogeneity (QOSI) supported using adaptive antenna arrays.

The introduction of heterogeneous services into the network will create what we term, *Quality Of Service Inhomogeneity (QoSI)*. Consider the scenario depicted in Figure 1. Assuming for now that the users in a cell are uniformly distributed and that all users are only voice users, it follows readily that a probability density function (pdf) describing the probability that a user located at an angle α to the base station will require a link to the base station with a BER of 10^{-3} will be uniform. However, if a limited number of users in the cell require services with BER requirements substantially stringer than that for voice communication the picture changes.

For instance, in Figure 1 most of the subscribers require voice service with typical BER requirements of 1×10^{-3} whereas another subscriber require a video service with a BER of 1×10^{-6} and yet another require a data service with a BER requirement of 1×10^{-8} . This means that the QoS pdf will exhibit peaks at the location of the video and data users. If it is furthermore assumed that all user can only transmit at a fixed rate, the increased QoS requirement would mean that the base station will need to assign more transmission time, as well as more signal power to the users with increased QoS requirements. In following section, the QoS pdf will be expanded to form the basis of a random access scheme.

III. SYSTEM DESCRIPTION

Referring back to the above mentioned example, the probable solution to providing for instance, the required data access to a number of users, would be to implement a contention multiple access protocol such as ALOHA, or, if better performance is required a s-ALOHA scheme [6]. In general, demand assignment protocols, such as Token Ring protocols, are not considered as these protocols require all users in the network to communicate with one another efficiently in order to ensure adequate system performance. Another solution is however possible. In this paper, we propose a system using variable antenna radiating patterns to create a virtual token that is moved through the network under control of the base station. We call this system an Adaptive Virtual Token Ring (AVTR) system.

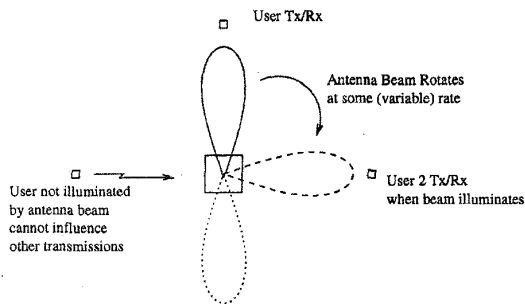


Fig. 2. System block diagram

Consider the system diagram shown in Figure 2. The system, first introduced in [7], consists of a standard base station radio transceiver with an antenna system, such as an adaptive antenna array, that can alter its radiating pattern. The radiating pattern of the antenna system is nominally a narrow beam which can be focussed in any direction. During multiple access operation, the base station rotates the antenna beam at some variable rate $\omega(\theta)$, where θ denotes the angular position of the user. When a user is illuminated by the beam, a successful transmission to the base station can be made. If the user is not illuminated by the base station antenna and it attempts to establish a connection, of course no collision will occur as the base station does not see the interfering user.

Comparing the operation of AVTR to Token Ring, the performance of AVTR can be deduced easily by drawing some analogies between the two systems. Therefore we assume that the antenna system can generate ideal radiation patterns with beam width δ rad. This would mean that a user is illuminated for exactly $T_s(\theta) = \delta/\omega(\theta)$ s, corresponding to a time slot size of T_s seconds. The period in which the user is illuminated by the narrow beam radiated from the base station can be seen as the period in which the user has control of the token in a token ring network. The only difference being that the user received the token under control of the base station, as opposed to its neighboring user. Furthermore, the number of users (or token consuming geographical areas) in the network can be calculated as

$$N = 2\pi/\delta \quad (1)$$

Building on the results for Token Ring networks presented in [6], the maximum performance of a standard Token Ring network is

$$U_{TR} = \frac{1}{1 + a/N} \quad (2)$$

where a denotes the propagation delay as a fraction of the packet size (which is assumed to be smaller than the packet size), T_s . The throughput of the AVTR protocol is however influenced by another factor. If two mobile subscribers are co-located, both will think that they have "received the token" simultaneously and will initiate transmissions to the base station at the same time causing a collision. Therefore, the maximum throughput of the AVTR protocol can be written as

$$U_{AVTR} = U_{TR}(1 - P_c) \quad (3)$$

where P_c denotes the probability that two users are located with angular separation of less than δ rad. Mathematically, this probability can be defined as

$$P_c = \max \left\{ \int_{\theta-\delta/2}^{\theta+\delta/2} P_{location}(\theta) d\theta \right\} \quad (4)$$

$$\text{where } \delta/2 \leq \theta \leq 2\pi - \delta/2$$

where $P_{location}$ is the probability density function describing the angular location of users in a cellular network. In [8] a thorough treatment of the modeling of the location of mobile users in a cellular network is presented. From (5) it is clear that the higher the probability of users being co-located, the lower the throughput of the network. If it is assumed that the user are uniformly distributed in the cell, (3) can be rewritten as

$$U_{AVTR} = \frac{4\pi^2 - \delta^2}{2\pi(2\pi + \delta a)} \quad (5)$$

From (5) it is clear that the performance of the system increases as the antenna beam becomes narrower. This performance is also shown in Figure 3.

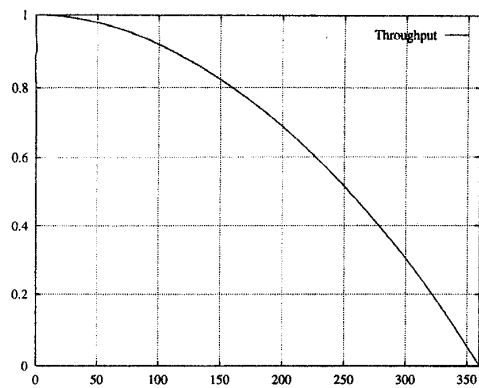


Fig. 3. Maximum throughput as a function of antenna beam width.

In addition to controlling access to the radio resources, the proposed AVTR scheme can be used to control the levels of service available to different users by varying the rotation speed of the antenna beam (creating variable token hold times), as well as the radiated power to each user. For instance users with high QoS requirements can be illuminated for a longer time (slower rate of moving the antenna beam) with higher gain than users with lower QoS requirements.

Furthermore, the system described above requires no change of the base station architecture except for the addition of the antenna system. This means that the overall system design is simpler than with, for instance, a s-ALOHA systems where some form of network synchronization is required.

IV. CONCLUSIONS

The system presented above provides a novel and easy way to increase the throughput of existing ALOHA networks. The system is simple to implement and can give networks substantial gains in throughput. We have shown that the system is conceptually equivalent to Token Ring networks, with the throughput being determined by the width of the antenna beam and the probability that users cannot be spatially separated by the antenna system.

As this paper has only introduced a new multiple access method, many open research questions remain. Firstly, a more rigorous mathematical analysis of the throughput and delay of the system is required. Specifically factors like the non-uniform speed of rotation and realizable antenna patterns needs to be taken into account. Also, many improvements can be made to the system. Firstly, Code Division Multiple Access (CDMA) techniques might be used to separate user that cannot be spatially separated by the antenna system, thereby effectively reducing P_c .

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