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Technological Issues: Closing the Digital Divide Through Resource Allocation Techniques

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CLOSING THE DIGITAL DIVIDE THROUGH RESOURCE ALLOCATION TECHNIQUES

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ABSTRACT

It is only after access to technology is assured that computer literacy can begin. Access is not simply having access to up-to-date technology; it should also include access to qualified teachers, appropriate software and Web content. Vital to this issue is the quality and quantity of the access.

The optimisation of the bandwidth use, obtained by implementing bandwidth allocation schemes and suited protocol solutions, will allow providing improved quality of service and reduced cost of broadband Internet access. This technology will allow the provision of QoS-based broadband services in hazardous environments and in areas where the technological development is less spread and the Internet isn't well delivered.

Resource allocation has become the most important technology in satellite and wireless networks. All satellite systems are limited by bandwidth and power, which are both expensive resources. Operators of satellite systems receive fixed allocations of these resources and as a result, are limited in the number of users they can support on one system. To combat this problem and to lower the costs for system operators, certain power and bandwidth conservation methods have been developed.

In the past, satellite systems were used to deliver telephony or transaction-based applications. Since telephony is a single application with a predefined bandwidth requirement, a simple resource allocation technique such as Demand Assigned Multiple Access (DAMA) is sufficient. A transaction-based application requires a simple ALOHA channel.

The development of Two-Way IP access systems, which support a variety of protocols and applications, has created the need for more complex resource allocation algorithms. Faced with a combination of real-time applications, such as Voice over IP, and non real-time applications that still require high bandwidth, such as e-mail transmission, resource allocation algorithms have had to work with two conflicting issues: Quality of Service and bandwidth consumption. As a result, Bandwidth On Demand (BOD) algorithms were developed to manage resource allocation and Quality of Service mechanisms were developed to identify the needs of different applications.

This paper discusses the application of different resource allocation

algorithms to different type of traffic. Using mathematical formulation it presents the bandwidth saving achieved by BOD for IP type of traffic.

I. INTRODUCTION

Satellite IP System

Satellite IP systems with star topology can be viewed as a combination of two subsystems. A forward link, and a return link sub systems. While the forward link system is responsible for the transmission of data from the base station (which is referred to as Hub), the return link system is responsible for the transmission of data from the remote terminals to the hub. The forward link system benefits from the advantage that the data is transmitted with a single carrier, in which the data is multiplexed in the time domain, and there are no synchronization issues between the terminals. The return link system has to deal with synchronization issues and manage the common resources between the terminals, in the time and frequency domains. Also, the management system, which resides in the hub, suffers from a satellite delay between the terminals and the hub, which complicate any feedback system implemented to manage terminals traffic.

The following is a simplified diagram of such a system:

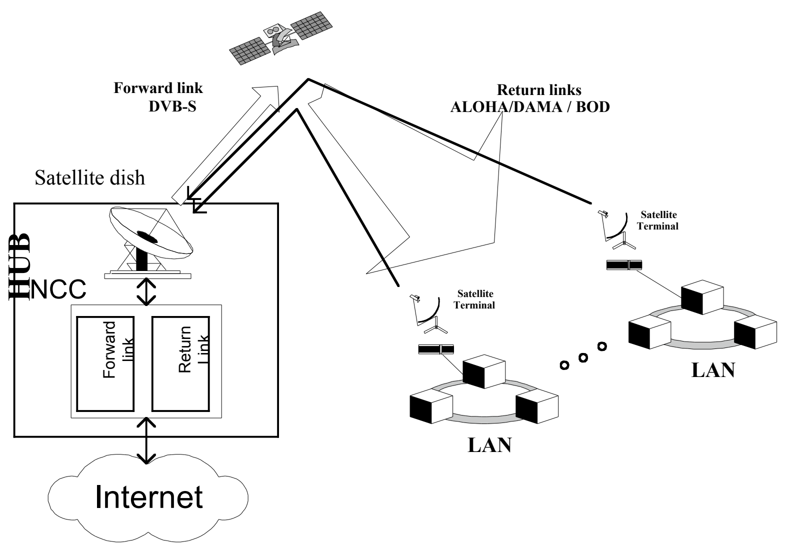

Figure 1: Satellite 2-way system

The satellite terminals in the figure support LAN, however for matter of discussion they can support any type of customer.

The paper discusses the management of the satellite bandwidth assigned to the return channel sub-system, and the way the system allocates bandwidth to the satellite terminals. Three major methods are considered – ALOHA, DAMA and BOD.

BOD Advantage

In contrast to access schemes such as ALOHA, that enable each terminal to use the channel on a contention based method, or DAMA which allocated fixed bandwidth to a terminal upon demand, the BOD algorithm, enables not only the assignment of fixed-size space segments to a customer, but also the allocation of a space segment and data rate that matches a customer's current needs. BOD is automatically configured based on the customer's immediate requirements and relevant stipulations of the system operator, which results with a dramatic improvement in satellite bandwidth utilization!

Paper Outline

This paper presents the concept of BOD, and compare the performance of a BOD system to DAMA and contention based (ALOHA) systems. The paper briefly describes the relation between BOD and IP-QoS, and presents the effect of BOD parameters on terminal QoS. Chapter II describe the different types of traffic, gives the motivation for the development of the BOD enabled systems. Chapter III give a detailed mathematical formulation for both DAMA and BOD, and provides results for comparison between the two. Finally chapter IV briefly describes the integration between BOD and IP-QOS.

II. TRAFFIC TYPES

Resource allocation technology has evolved in order to support different traffic types. The main characteristics of the old satellite systems, was the requirement to support single or very few types of traffic on each terminal, resulting in very simple resource allocation techniques. The two main types were - transaction based applications, and voice traffic. As the number of different applications grew, and the requirement to support variety of protocols and variable data rates, those systems tried to adopt the simplified allocation techniques to the changing environment. The revolution of IP communication has made these efforts fail. Thus a need for a new type of resource allocation technique was created.

In the following section we describe three different types of traffic and the appropriate allocation techniques.

Transaction

Bank transactions or client server applications are characterised by small packets (with predefined size), very low data rates and requirement for fast response. This type of traffic is best suitable for contention based resource allocation. Such allocation schemes are the ALOHA and Slotted ALOHA [1]. A channel is constantly open for transmission from different terminals, where many terminals access the same channel. If two terminals transmits at the same time to the channel, a collision occurs and data is lost, but since these types of applications rarely transmits very few bytes of information, a system can be designed in which the probability for collision is very low.

The following example demonstrates the concept:

Number of terminal is 100. Each terminal supports a single source of information, which transmits at peak hour 3 transactions per minute. Transaction size is 100 bytes.

Since:

$$BW_{Total} = N\frac{T_r}{60}\frac{L}{8} = \frac{NT_rL}{480}$$

....

(1)

Where:

N = Number of terminals,

T_r = Number of transactions per minute

L = Length of transaction in bytes

η = Channel utilization

For $\eta = 0.15$, we get:

$$BW_{Total} = \frac{100*3*100*8}{60*0.15} = 26{,}666bps$$

Voice

Voice application is also typical for many satellite systems. It is characterized by two states: Either the voice circuit is operating, or is off. Establishment of a voice circuit may take several second. When established data rate is much higher than transactions and is between 8 to 64 Kbps, depending on the voice compression. Once established, the voice circuit requires constant bit rate with low jitter. Thus a DAMA based system is ideal. DAMA systems negotiate an establishment of a satellite link between the terminal and the NCC. Upon approval, a link with constant bit rate is available for the period of the call.

Considering the above example, with voice application instead of transactions. Assuming a voice call requires 8 Kbps, assuming the probability of a terminal to connect is *p*=0.5. According to the formulation in chapter II, we chose $m_{DAMA} = 3$ to get $q_{DAMA} = 99.7\%$, the probability to successfully connect all requesting terminals.

Now, let us calculate the required bandwidth to support this application using Slotted ALOHA, and DAMA.

For the ALOHA system, according to (1), and calculating only for the average scenario, where *pN* = 50, and replacing $\frac{T_r L}{480}$ by the rate of a voice channel:

$$BW_{Aloha} = \frac{50*8Kbps}{0.15} = 2.67Mbps$$

For a DAMA system, using equation (3), we get:

$$B_{TDAMA} = NpB_{\max} + m_{DAMA}\sigma_{DAMA} = 100*0.5*8 + 3\sqrt{100*0.5*0.5}*8 = 520Kbps$$

Which is far less than required by the Slotted ALOHA system.

IP Traffic

In contrast to the two traffic types described above, most IP based applications use variable bit rate. The bit rate required from the terminal depends on the type of applications, number of users, time of day and also the behaviour of the IP network supporting the satellite system. Thus while some of the applications such as VoIP and Video conferencing use pre defined constant bit rate, others such as e-mail, browsing, FTP use variable bit rate. Thus, the data rate, which should be supported by the terminal is variable and cannot be estimated in advanced.

The only known facts are: the maximal transmission rate of the terminal, and the QoS requirements of each application. It is quite clear that a simple contention based scheme, or even a DAMA system will not provide a suitable solution. For such cases, a more adaptive system is used, mainly Bandwidth On Demand.

The following is an example for IP traffic:

Assume the same 100 terminals, but with the traffic composed of multiple protocols, resulting with the following statistics:

The traffic is a random variable $\bar{x}$ with normal distribution $N(\bar{x},\sigma)$ where

$\bar{x} = 32Kbps$, $\sigma = 16Kbps$

In order to satisfy terminal requirements with probability of 99.7 %, one must allocate data rate of:

$B = \bar{x} + 3\sigma = 32 + 48 = 80Kbps$

Using DAMA, according to equation (3), assuming the same distribution of connected terminals as in the voice example above, we get:

$$B_{TDAMA} = NpB_{\max} + m_{DAMA}\sigma_{DAMA} = 100*0.5*80 + 3\sqrt{100*0.5*0.5}*80 = 5.2Mbps$$

Using BOD according to (8), and choosing $m_{BOD} = 3$, to achieve $q_{BOD} = 99.7\%$, the probability to successfully fulfil all terminals requirements, we get:

$$B_{T_{BOD}} = Np\bar{x} + m_{BOD}\sigma_{BOD} = 100*0.5*32 + 3\sqrt{100[0.5*0.5*32^2 + 0.5*16^2]} = 2.188Mbps$$

Which is 42% of the bandwidth required by the DAMA system.

III. RESOURCE SAVING METHODS [2]

General Descriptions

Features such as DAMA, BOD and APC all help to conserve satellite resources. Demand Assigned Multiple Access, as the name implies, allocates resources when they are needed. BOD performs a similar function, although it also adapts to actual traffic. This means that BOD allocates the exact amount of bandwidth needed and continues to monitor the user, allocating smaller or larger bandwidth when and if needs change.

General Scenario

For sake of simplicity, we assume the model where all users are identical. For N users, each user, *i*, requires a bandwidth αx where α is the activity random value, which has the value 1 with probability P and the value 0 otherwise. The bandwidth of an active user x_i has an average value $\bar{x}$ and a variance σ^2. In the following two sections, we will analyse the bandwidth requirements of the model, when using DAMA and BOD.

DAMA

DAMA is designed to allocate bandwidth only when it is required. For a system without DAMA the total bandwidth, $B_{T,}$ is given by

$$B_T = NB_{\max}$$

....

(2)

We can assume that $B_{\max} = \bar{x} + m\sigma$ is the maximal bandwidth allocated to fill the requests of a terminal with probability q, by choosing the proper factor m.

The bandwidth allocated with DAMA is

$$B_{T_{DAMA}} = NpB_{\max} + m_{DAMA}\sigma_{DAMA} = NpB_{\max} + m_{DAMA}\sqrt{Np(1-p)}B_{\max} \qquad (3)$$

where σ_{DAMA} is the standard deviation with DAMA given by

$$\sigma^2_{DAMA} = Np(1-p)B^2_{\max} \qquad (4)$$

and m_{DAMA} is chosen to fill the system's requests with probability q_{DAMA}.

If we define the activity factor, α_A, as

$$\frac{B_{T_{DAMA}}}{B_T} = \alpha_A \qquad (5)$$

Then

$$B_{T_{DAMA}} = \alpha_A \cdot N \cdot B_{\max} \qquad (6)$$

The improvement from DAMA is due to the activity factor, which, in general, can be considered to be between .1 and 1. The activity factor depends on several factors, including the type of users, the type of applications, the day of the week and the time of the day.

BOD

BOD is similar to DAMA, but has added capabilities. BOD allocates the space segment and data rate according to a customer's current needs. If the customer at some point requires more or less bandwidth, the BOD senses this and acts accordingly. With BOD, when *N* users are connected, they consume bandwidth, which is equal or smaller than $NB\max$. While for DAMA they will consume exactly $NB\max$. Thus it is possible to assign less BW to the system, and maintain the same blocking probability.

However, it is necessary to allocate larger than average bandwidth. Assume that the bandwidth consumption of each remote terminal is a random variable x_i with expected value $\bar{x}$, and with a standard deviation of σ. In order to simplify the explanation, assume that all remote terminals have the same mean and standard deviation. The peak rate allocated to each remote terminal is $\bar{x} + m_1\sigma$, where m_1 is such that the probability of a single remote terminal to consume bandwidth is between 0 and $\bar{x} + m_1\sigma$ is q_1. For example, in the normal distribution m_1=3 corresponds to

q_1 = .997 according to the error function integral:

$$q_1(m_1) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{m_1} e^{-x^2/2}dx \qquad (7)$$

The bandwidth allocated with BOD is

$$B_{TBOD} = Np\bar{x} + m_{BOD}\sigma_{BOD} = Np\bar{x} + m_{BOD}\sqrt{N\left[p(1-p)\bar{x}^2 + p\sigma^2\right]}$$ (8)

where σ_{BOD} is the standard deviation with BOD given by

$$\sigma^2_{BOD} = N\left[p(1-p)\bar{x}^2 + p\sigma^2\right]$$ (9)

and m_{BOD} is chosen to fill the system's requests with probability q_{BOD}.

The savings factor of BOD relative to DAMA, $\square_B$, is

$$\square_B = \frac{B_{TBOD}}{B_{TDAMA}} = \frac{Np\bar{x} + m_{BOD}\sqrt{N\left[p(1-p)\bar{x}^2 + p\sigma^2\right]}}{NpB_{max} + m_{DAMA}\sqrt{Np(1-p)}B_{max}} = \frac{\bar{x}/B_{max} + m_{BOD}\sqrt{\left[(1-p)\bar{x}^2 + \sigma^2\right]/NpB^2_{max}}}{1 + m_{DAMA}\sqrt{(1-p)/Np}}$$ (10)

Note that $\square_B \; \square \; \square \; \frac{\bar{x}}{B_{max}}$

The total savings gained by using DAMA and BOD together is

$$\square_{Total} = \square_A \cdot \square_B$$ (11)

Figure 2a compares the BW consumption for a given number of users, between DAMA and BOD system. Figure 2b shows the BW consumption of DAMA vs. BoD for fixed QoS (m) as a function of number of users (N).

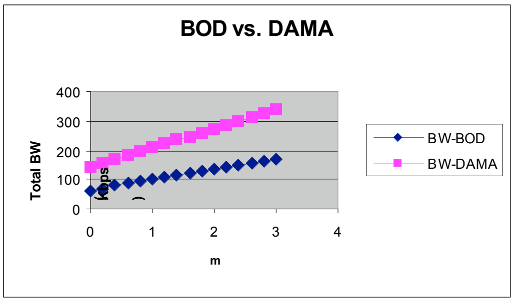

Figure 2a: Total BW for BOD and DAMA with 20 Active users

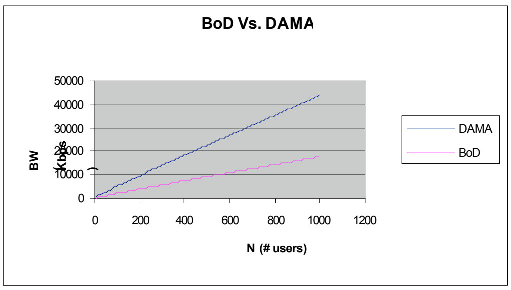

Figure 2b: Total BW for BOD and

From Figure 2a, the BW savings of BOD versus DAMA increases as we decrease the blocking probability (increasing quality of service) by increasing *m.* From Figure 2b, the BW savings of BOD versus DAMA increases as the number of terminals increases.

IV. BOD AND IP-QOS

There is a relation between BOD and the applications supported by it. It can be shown that bandwidth changes due to BOD operation, effect performance of applications supported by the satellite terminal. The effect can either enhance or reduce performance. It is therefore required to enable BOD to take into consideration applications supported by the terminal at a specific moment. On the other hand to application bandwidth consumption has to be limited according to available bandwidth. This is done by integration of BOD functions and IP-QoS in the satellite terminal. The following figure describes the basic structure of the terminal.

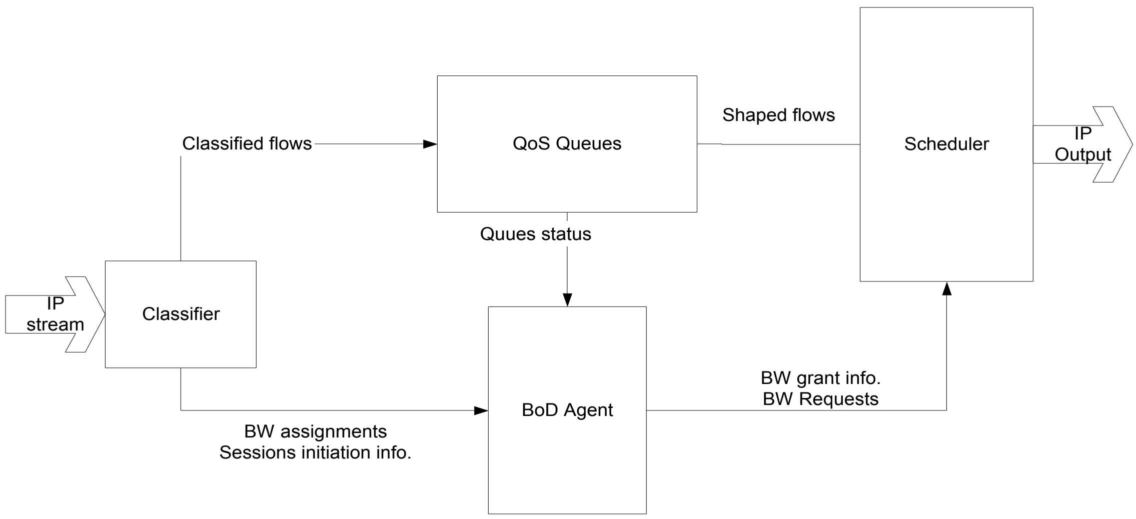

Figure 3: Simplified drawing of terminal BOD system

The BOD agent is responsible for generating Bandwidth Requests (BR) according to measurements done on the QoS queues. It then sends the BR to the BOD server at the Hub (Not shown here) using the return link channel. The BOD server according to user parameters, users Service Level Agreement (SLA) and to system state generates a BW allocation. The BOD agent controls scheduler operation based on knowledge of allocated bandwidth. The BR request is calculated by one of the following methods, or by a combination of:

- Rate estimation
- Volume estimation
- Application session.

Each application supported by the BOD is measured with the suitable method. I.e. Internet browsing is measured using rate-based estimation, while VoIP is measured according to session. E-mail is measured according to volume.

The BR is adapted to the type of traffic flowing through the terminal, taking into consideration issues such as application type, priority, sensitivity to delay and jitter.

CONCLUSIONS

The satellite communication system is based on an architecture that allows multiple techniques to maximize the space segment allocated to multiple Return channels. For IP based application the most efficient method for bandwidth management is the Bandwidth On Demand. In comparison to techniques such as DAMA, it requires 50% less bandwidth to provide the same service.

Such saving in broadband Internet access is an important step towards closing the social gaps throughout our society, particularly among young people. By providing affordable access to technology and information we can ensure that all children step into the 21st Century together.

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