# ADAPTIVE HANDLING OF THE BANDWIDTH HETEROGENEITY IN COLLABORATIVE VIRTUAL ENVIRONMENTS

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## Abstract

*This article proposes a mechanism for improving the collaboration in a distributed virtual environment with heterogeneous networking, adapting the operation of the virtual environment, to the varying conditions of the network. Normally, a user who participates in a virtual environment with other users, does not have to his disposition the ideal network conditions for the transmission and reception of the application data. The fundamental idea is that once a station detects the diminution in the available network bandwidth, it starts predicting, by means of Dead Reckoning, the following movements of the other users with the purpose of maintaining the consistency between its virtual world and worlds of the other users. In a client-server environment, the server will send messages to the stations of the users who participate in the virtual world, depending on the conditions of each one of them, grouping the stations in multicast groups according to the speed of the incoming messages to each node, as implemented first in the Switchboard Architecture, developed by one of the authors in his doctoral dissertation. In the work describe in this paper, experiments were conducted both in local area and wide area networks, simulating adverse networking conditions that lead to a reduction in available bandwidth. Our experiments show that the combination of the Switchboard Architecture and the Dead Reckoning algorithm, allow for a significant reduction in network bandwidth, while maintaining the usability of the networked environment under adverse network conditions.*

## Keywords
Virtual Reality, Collaborative Virtual Environments, Computer Networks, Communications Protocols.

## 1. INTRODUCTION

In distributed and collaborative virtual environments, the bandwidth of the network is a critical and scarce resource, especially when a consistent shared state with real-time interaction is to be implemented. The large amount of information that is exchanged among nodes diminishes the scalability of the system, since increases in the number of organizations and participant clients lead to exponential increases in the number of messages, causing network degradation. Techniques such as Dead Reckoning, associated with Switch Board Architecture (SBA), explained later in this paper, allow for a reduction in the amount of messages, thereby increasing the scalability of the system.

This article proposes a model in which stations are grouped according to the conditions of their connections, and the update messages are sent in differential time intervals and according to the conditions of each one, maintaining the consistency of the virtual world by means of Dead Reckoning, as mechanism to reduce the use of the bandwidth, thereby creating a model that adapts the virtual world to the conditions of the network at each node.

This article is organized as follows: Section one briefly describes the related works. Section two proposes a model of the adaptive handling of the heterogeneity of the network. In section three is detailed how the experiment was. In section four appear the quantitative results of the experiment and its analysis, and finally the conclusions and future work are presented.

## 2. RELATED WORK

In an ideal Distributed Virtual Environment (DVE), each participant would have network conditions allowing him/her to maintain a perfectly consistent copy of the virtual world. In the real world, users have heterogeneous conditions, which can lead to unbalanced advantages and unfairness, affecting the collaboration amongst them. Designers of a DVE can either provide a controlled environment granting homogeneous conditions to every participant or handle heterogeneity.

Controlled environments are distributed applications in which the minimum characteristics are predefined, as well as the participating computers, elements and conditions of the network. Participants who want to take part of the virtual environments, must have this type of environments. Papers such as [1] describe DVEs that run under controlled environments.

Heterogeneity in network conditions include physical network characteristics, such as Latency and "Jitter"; in addition to differences in network conditions available for each user. This means that the heterogeneous conditions must be dealed with in such a way that their impact on the virtual environment be reduced as much as possible. Numerous investigations with this aim have been undertaken; to reduce the impact of heterogeneity on the virtual world, on one hand, and to adapt the distributed virtual environment to the heterogeneous conditions, on the other hand.

Several projects aim at reducing the traffic in the network by reducing the number of messages. That is the approach taken by Broll et.al [1].

Michael R. Macedonia et. al. [2] describe a way to map multicast groups to geographic regions thereby reducing traffic by in two ways: first by sending a message to many users (multicast) and second by sending only information that is pertinent to other users that share a multicast group.

In search of maintaining optimal network conditions, Funkhouser [3] proposes a combination of a Client/Server architecture with multicast groups. Each entity sends update messages to a server, and the server sends the update messages either to a multicast group or to other servers.

Yang and Lee [4], propose multicast group with to manage the position of the avatar. Based on this information the decision to include or not to the user within a multicast group, associated to region, is taken.

Shirmohammadi and Georganas [5] propose to send mostly differential messages amongst users. Differential messages provide relevant information, referring to the difference between the previous state and the present state of a participant entity in virtual environment.

Trefftz and Marsic [6], propose to cache messages at the server. Singhal and Zyda [7] propose predictions of the state of the entities by means of Dead Reckoning. Juan Jaramillo et al [11] as well propose an improvement of the model described by Singhal and Zyda, trying to obtain scalability in distributed environments.

Other researchers have focused on allowing users limited resources to have access to DEV application, such as the proposal by Trefftz, Zyda et. al. [8]. They propose to map the domain of the problem to the solution of a mathematical model which obtains an optimal configuration for all the stations.

Collaboration in CVEs has been approached differently. Macedonian, Brutzman. et al [9], demonstrate that a good collaborative virtual environment must have an end-to-end delay not greater than 100 milliseconds. Therefore, only those messages that are strictly necessary to maintain the consistency of virtual worlds are sent.

## 3. ADAPTIVE HANDLING OF NETWORK HETEROGENEITY

This work proposes the combination of the Switch Board Architecture [8], and the use of the Dead Reckoning. Multicast groups are used to group together the participants according to their network speed. These multicast groups are handled by a server that acts like a referee administering the multicast groups in according to the different transmission frequencies, and to the speed of the members in each group.

Even though the Switchboard Architecture works on the heterogeneity of the nodes, his philosophy can extend to heterogeneities in other aspects, in this case, to heterogeneity in network connections.

### 3.1 The Concept of the Switch Board Architecture and Multicast Groups

The server in the" Switch Board Architecture" (SBA), as it was originally proposed, receives updates from the clients to form a matrix of variables that represent the conditions of a workstation, combined with the preferences of the users. Each row in the SBA corresponds to a variable of the system of each station or user (Figure 1). The update messages of a variable for all the participants are received and stored in a small cache. There is a clock that determines when the messages in the group kept in that cache are sent to the clients that have subscribed to the group.

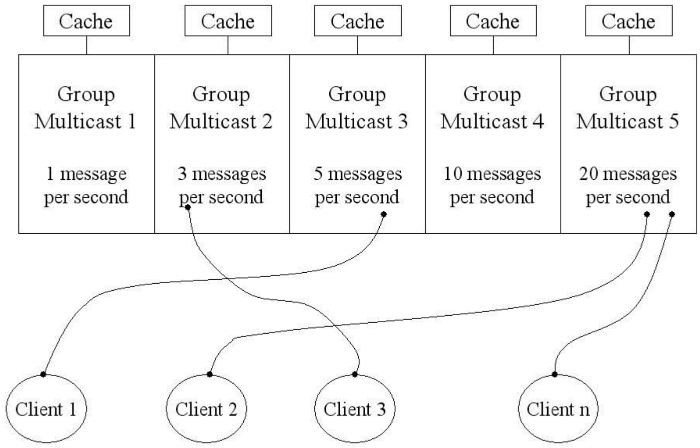


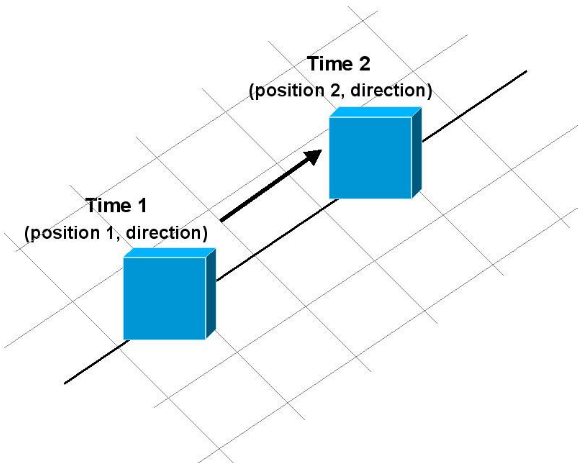

Figure 1: Switch Board Architecture.

Based on the previous concept, we introduce a new variable, named Network Condition Condition, which is measured by means of the RTP/RTCP protocol. For the purpose of this work, the matrix has only a row and its columns represent a rate of messages per second. Each column is associated to a multicast group. The messages to that multicast group are stored in cache, and they are then transmitted to the clients according to the frequency of each column.

A client will receive the updates of the virtual world from other clients based on its network conditions. The SBA acts like a buffer that adapts to the heterogeneous conditions of each participant in the DVE. The conditions of network are checked by each one of the clients periodically, and this information is sent to the server. The server, in turn, decides whether to retire a client from a multicast group to tie it to another one, in order to increase or to diminish the frequency of the messages that it is able to receive.

## 3.2 Dead Reckoning

"Dead Reckoning" proposes to predict or to approximate the state of an entity (its position, speed, acceleration, among others), based in the information stored in a local cache, during the time that no update packages of each client are received. The net effect is to reduce the transmission frequency of update packages, obtaining a reduction in the traffic of the network without losing consistency in the collaborative virtual environment




. Figure 2: Prediction of Movement by Dead Reckoning

This prediction is temporary, update messages do not stop altogether, but their frequency is diminished. Therefore, the loss of consistency is not significant. The Dead Reckoning protocol is used in this work to predict the movements or positions of the other participants of the virtual world while update messages are not received, this happens when the client is moved from a multicast group to one of smaller frequencies in the SBA.

## 4. Configuration of the experiment

In order to validate the idea described in this document, a simple DVE game, called "The Cubes", was implemented in Java 2 and Java 3D. The technological and communications infrastructure used (Figure 3) to conduct the tests was done on four identical machines, with AMD processor running at 1,7 Ghz, 128 Mb in RAM, 100 Mbps network adapters and 56 Kbps modems. One of them acted as a server, and the others as clients. A LAN of 100 Mbps, and active communication elements were used to configure a WAN implemented over ISDN lines.

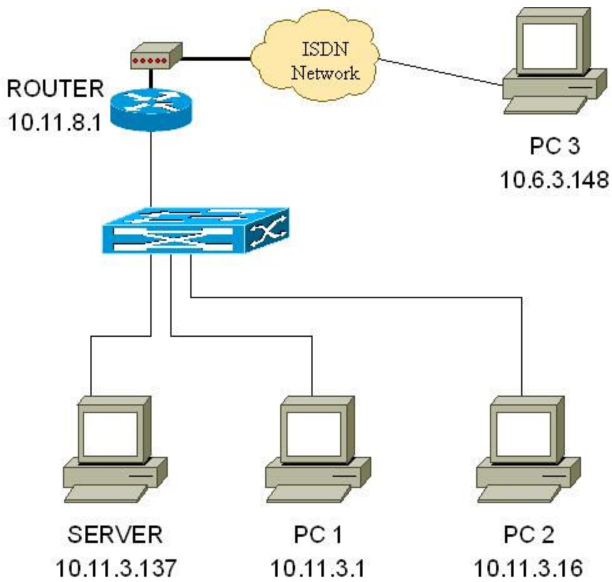



Figure 3: Network created for the experiment.

The base application of the experiment (The Cubes) was developed by the Helmuth Trefftz in 2001 and modified by Andrés Quiroz Hernandez in July of 2002. The Cubes is a simple networked virtual reality game that allows the use of two different protocols: UDP and RTP in two different modalities Unicast and Multicast, thus allowing four modalities of game, with experimental aims. For this experiment the game was implemented with multicast and RTP/RTCP.

The objective of the game in original version is to capture the largest number of cones. In order to capture a cone the use has to walk across it. In the implemented version, the cones must simultaneously be touched at least by two participants of the game, in order to obtain points for both. This rule enforces collaboration amongst users. The elements in the scene are the following ones:

The land, is a plane on top of which the objects are located.
Cubes are used to represent the users (simple avatars).
The cones are the elements that users have to capture. Cones change their color as soon as they are touched by two users.

The server program has the following functions:

- Acts as a referee, determining when two users have captured a cone.
- Administers multicast groups with the SBA concept and maintains cache of messages.
- Registers all the participants of the game in multicast group number 5.
- Determines positions for the buckets randomly.
- Warns the clients of the beginning of the game.
- Receives the updates messages and registers the score of the clients, updating an inventory of cones.

- Sends a reinforcement message, ratifying the event in case there are lost messages for some client.
- When all the buckets have been touched, the server sends a message of game end, with a final summary of the score of each client. At the end of the game, the communications are closed.
- Provides the user with information about the activities on each multicast group.

The client program has the following functions:

- Register or to connect to the game.
- Makes a census (Benchmark) of the conditions of network of his connection. This census is made periodically during the development of the game.
- Sends messages indicating the identification of the touched cone and the user and sends messages to other clients to the change the color of the grabbed cone in their scenes.
- Gathers statistics of the state of the connection and it stores them in a file.

For the communication, in addition to the multicast transport protocol, Real Time Protocol (RTP) was used to measure the state of the network.

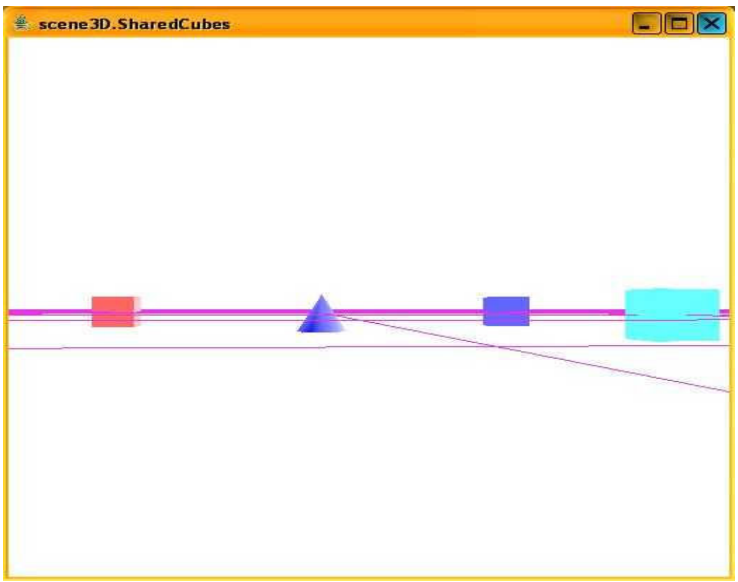
Figure 4: “The Cubes” game.

RTCP was used to allow the system to sense the quality of the service and the transport of the information between the participants in a session in course. This was the mechanism used to obtain data about the connections of each user. RTP provides data transportation in real time, such as audio and interactive video. Those services include the type identification, enumeration or sequence of the payload, "timestamping" and supervision of the delivery, among other characteristics. RTP works typically on UDP.

## 5. Simulation and Results

In order to test the proposed model, the program was run without SBA, nor "Dead Reckoning" (control group). These two characteristics were later activated in the game (experimental group).

The average time between messages, as shown in figures 5 and 6, increases when SBA and "Dead Reckoning" are used. This means that the amount of messages that travel by the network diminishes significantly, according to the statistics captured with RTP/RTCP, taking the time in milliseconds between incoming packages to each station.



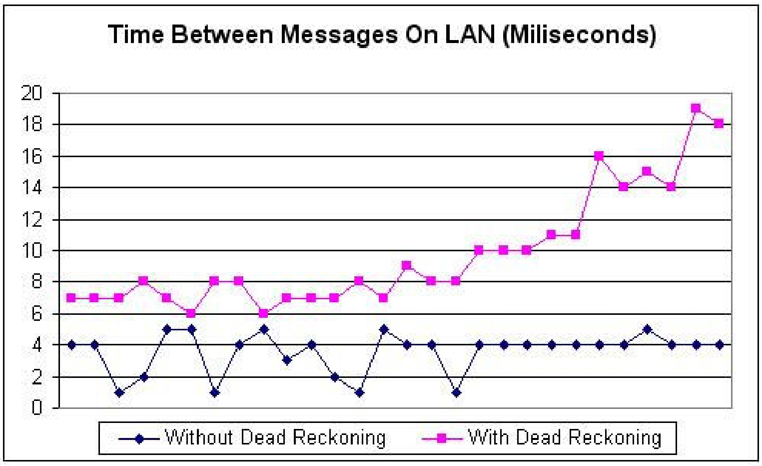



Figure 5: Experiment on a LAN

The obtained statistics indicate that when control mechanisms for the sending and/or the reception of messages are not deployed, the messages flood the network, in this case with an average rate of 3,57 milliseconds between messages. With the use of the proposed techniques, this rate is increased to 9,75 milliseconds between messages, allowing that the traffic can be handled properly by all stations.

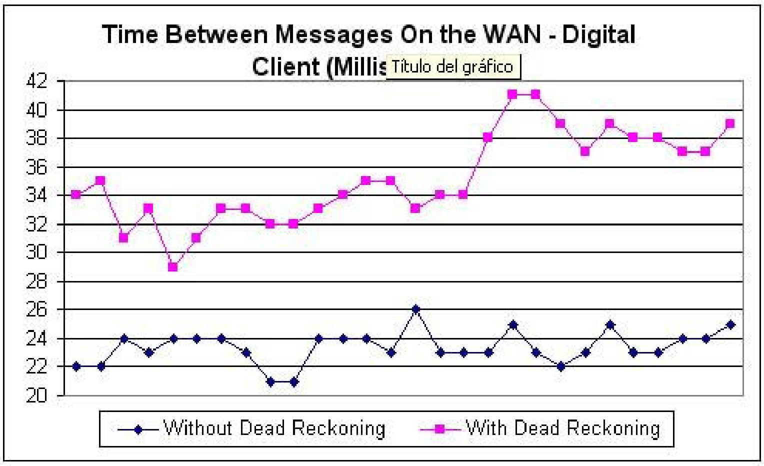



Figure 6: Experiment on a WAN (Digital)

Protocol RTP/RTCP provided information every 0.3 seconds, around 1.762 samples during ten minutes, the average of time the games last

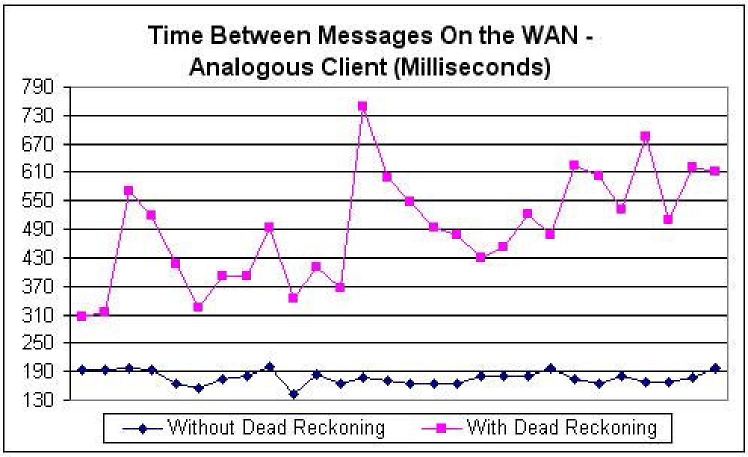



Figure 7: Experiment on a WAN (Digital)

The experiment was repeated connecting a station outside the LAN, with the purpose of creating real network heterogeneity. A WAN, with two "remote" connections was created, one through ISDN line allowing digital devices of end to end, and another connection through modem, using an analogous line. The results are described in figure 7.

The clients with low quality network conditions, as those in the WAN, also benefit from the proposed model, as the results show. Using protocol RTP/RTCP it was additionally possible to measure the amount of messages which arrived out-of-order, that is to say, outside the sequence. In a WAN the percentage of out-of-order messages received by one of the clients *without* SBA and Dead Reckoning was of a 60% in average. In the presence of SBA and Dead Reckoning, the out-of-order percentage was reduced to a 20%.

## 6. Conclusions and Future Work

The characteristics of the distributed virtual environments networks can impact the distribution of messages in such a way that both consistency and effective collaboration can be severely affected. The results of the reported experiment, demonstrate that it is possible to diminish the number of messages in the network, favouring the environments and allowing stations with heterogeneous network to interact with users who present/display better conditions in their networks, without causing a perceptible diminution of world consistency.

The combination of the SBA and "Dead Reckoning", are very efficient tools to diminish the traffic of the networks.

In the future, we plan to incorporate the model of combinatorial multicast that developed by the researcher Jaramillo, et al. [11].

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