Multi-Satellite DVB-RCS System with RCST based on Software Defined Radio

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Abstract— **Multi-mode satellite terminals are actually the most desired devices on the market, thanks to their flexibility and suitability. A multi-mode radio communication terminal is a terminal allowing two or more transmission mode. In the last few years many research resources have been invested in the study of this new type of terminal. In this work, we define a multi-mode terminal as a terminal capable of communicating both with a Bent-Pipe (BP) satellite and with an On-Board Processor (OBP) satellite and dynamically setting its transmission parameters (e.g. transmission power and code rate). In order to realize this multi-mode functionality, the most suitable technology is the Software Defined Radio (SDR). The SDR is a set of Hardware and Software technologies that allow one to obtain reconfigurable architectures for network and wireless terminals. The goal of our work is to plan a satellite system based on Digital Video Broadcast with the Return Channel Satellite (DVB-RCS) standard in which the Return Channel Satellite Terminals (RCSTs) are able to adapt it to the channel state, configuring the transmission chain via software, respecting a certain Quality of Service (QoS) constraint on the Packet Error Rate (PER).**

Keywords-DVB-RCS, SDR, Multi-Mode Terminal, Markov Chai.

I. INTRODUCTION

The recent increasing of multimedia application with the concomitant growth in the satellite communications have pushed the research in the study of new terminals capable of working with different technologies. In response to this, the next generation of satellite terminals must include multiple interface technologies in order to allow interoperability between different communications systems.

Software defined radio should be the solution to the described problems. Thus, a SDR system is a radio communication system which can tune dynamically some transmission parameters by means of a programmable hardware which is controlled by software.

The new types of terminals that use the SDR technique are called multi-mode terminals. In our study, we intend that a multi-mode terminal is a terminal capable of communicating both with a BP satellite and with an OBP satellite. The goal of our work is to plan a satellite system based on the DVB-RCS standard [1] in which the RCSTs are able to adapt it to the channel state, configuring the transmission chain via software, respecting a certain QoS constraint on the PER. For this purpose, an analysis on satellite channel under *Additive White Gaussian Noise* (AWGN) has been led out in order to obtain Markov chain model useful to test the SDR platform. Finally, a c++ simulation tool has been realized to validate the efficiency of proposed system.

In the following, a description of satellite system is given in section II (in particular DVB-RCS standard, SDR module and channel model have been explained), section III describe the employed simulation tool and the system performance, while conclusions are summarised in section IV.

II. SATELLITE REFERENCE SYSTEM

A. DVB-RCS ARCHITECTURE

In this paper a DVB-RCS architecture is considered. In our system, we consider two satellites: the first one with On Board Processor, that improve the platform performances; and the other one is a simple bent-pipe satellite. In Fig. 1 the most relevant elements of the DVB-RCS Network are shown ([1],[2],[3]):

- RCST, denotes each terminal that accesses the network. It can be of four different types on the basis of different bandwidth capacity: RCST A (144 Kbps), B (384 Kbps), C (1024 Kbps), D (2048 Kbps).
- *Network Control Center* (NCC), it has to manage the access and allocate the band for all RCSTs.
- Gateway and Feeders are the elements for receiving and transmitting information outside the network.

The satellite medium access scheme is based on a Multi-*Frequency Time Division Multiple Access* (MF-TDMA) approach.

The DVB-RCS standard provides five allocation request types [1]. They can be mixed in order to meet the RCST/NCC capabilities and the QoS requirements:

- *Continuous Rate Assignment* (CRA): is a fixed capacity negotiated between the RCST and the NCC. It is maintained across frames until a new negotiation takes place.
- *Rate Based Dynamic Capacity* (RBDC): it is a rate request, i.e. bytes/frame. The request has an absolute meaning and therefore the last one will overwrite all previous RBDC requests from the same RCST. The value of the RBDC request is subjected to a maximum rate limit that will be negotiated between the RCST and the NCC.
- *Volume Based Dynamic Capacity* (VBDC): is a volume capacity request, i.e., bytes. The request has a cumulative

meaning.

- *Absolute Volume Based Dynamic Capacity* (AVBDC): is similar to the VBDC request. It has an absolute meaning, i.e., it will overwrite any previous request of the same type.
- *Free Capacity Assignment* (FCA): it tries to assign the not allocated band

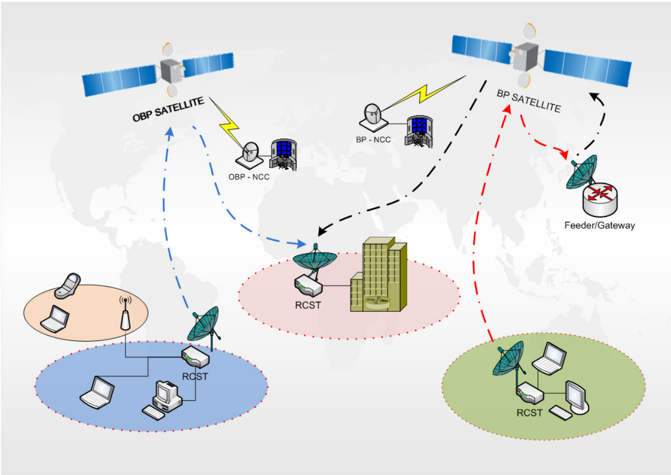

Fig. 1 Satellite system architecture.

B. *SDR MODULE*

We can see the SDR platform as a collection of hardware and software technologies that allows reconfigurable system architectures for wireless networks and user terminals. SDR provides an efficient and comparatively inexpensive solution to the problem of building multi-mode, multi-band multifunctional wireless devices that can be adapted, updated or enhanced by using software upgrades ([4],[5],[6]).

A typical digital radio system is mainly based on a superheterodyne structure, in which the stadiums at *radio frequency* (RF) and at *intermediary frequency* (IF) are totally implemented in analogical way and the digital hardware is placed only in *base band* (BB). Instead, in a SDR system, the transceiver is mainly realized through a single general digital hardware based on processors that implement in software the functions of the stadiums that are typically executed with analogical hardware. Therefore, with a suitable base hardware, only modifying the software it is possible to have different or additional functionalities, obtaining many modalities ([5] ,[6]).

A possible functional architecture of a multi-mode terminal utilises a *Digital Signal Processor* (DSP), that essentially performs the coding/decoding, and a FPGA that implements modulation/demodulation operations. Both devices form, de facto, the SDR module of the terminal.

In our work the re-configurability is obtained programming the logic circuit of SDR platform. Therefore the terminal can adapt it to the channel state setting via software the transmission chain. These considerations bring us to introduce the *Supervisor* (SPV) element ([7],[8]): on the basis of inputs coming from upper layer and from the information on the channel state provided by an estimator, the SPV is able to produce optimized directives and parametric values to the opportune reconfigurable adaptive blocks. In accordance with an inference algorithm, this is planned in an appropriate way. A scheme of principle of the SPV block is the following: the level of required QoS, represented by PER and bit rate, is provided to the MAC level, while the information on the channel state is originated by the *Physical* (PHY) level.

The SPV algorithm calculates and provides to the MAC level the pair bit-rate/PER, moreover other information are returned (maximum bit rate available or least available PER), that the MAC layer could eventually use for performing some optimizations. Instead, the optimal combination of coding parameters (coding rate and length of the coding block), transmission power and used satellite type are returned to the PHY level.

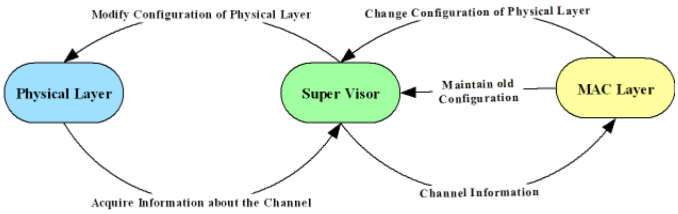

Fig. 2 Operation scheme of SPV.

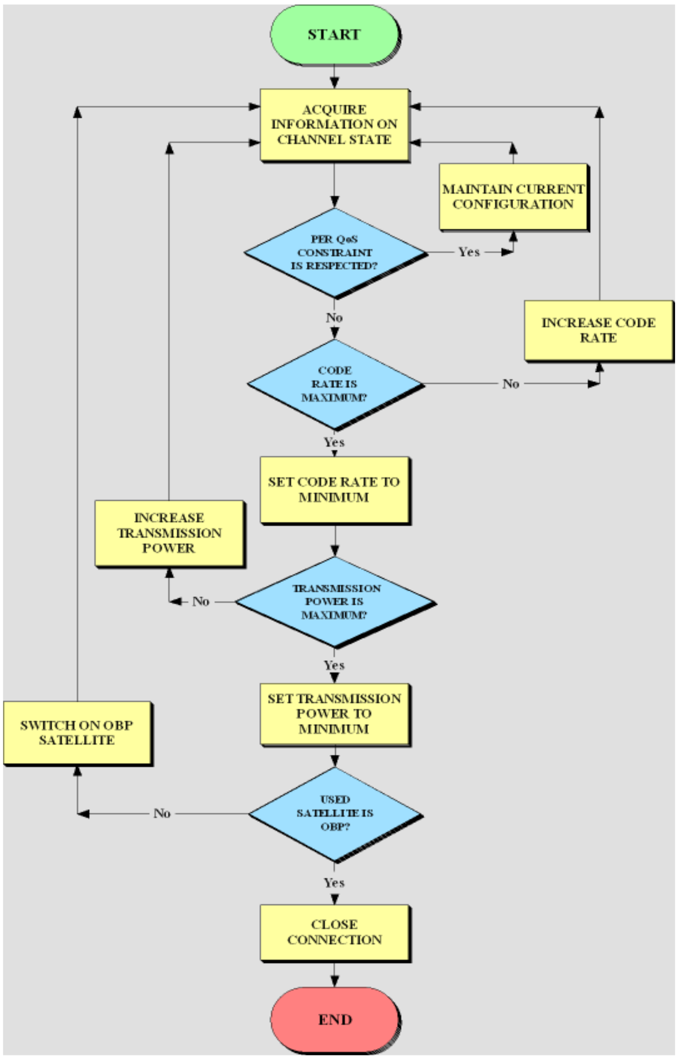

Fig. 3 SPV Algorithm flowchart.

In Fig. 2 the exchange messages are schematized: the SPV acquires information on the channel condition from an estimator and sends them to the MAC level; the MAC, therefore, sends a return message to the SPV in which it is communicated if the hardware must be reconfigured or not. If it is not necessary to change the transmission parameters, the SPV continues its phase of monitoring, acquiring information on the satellite channel; otherwise it will make a change via software on the transmission chain, trying to improve the performances.

The SPV makes the reconfiguration of the SDR module following these priorities: 1) change of the coding rate; 2) change of the transmission power; 3) switch on a different satellite. In Figure 3 we show the flowchart of SPV algorithm: SPV acquires information on channel state and it verifies if the PER QoS constraint is violated; this constraint consists of a PER percentage to respect (in particular the system must guarantee a PER less than 10^{-6}, *Quasi Error Free*, QES, transmission). If the constraint is violated then a hardware configuration change is necessary, so it verifies if the code rate is already the maximum and if it is false, the SPV increase it otherwise it sets the code rate to the minimum value and it tries to increase transmission power; if this operation can not be performed because the power is already to the maximum then SPV tries to switch on OBP satellite; if the RCST is already logged on OBP satellite, no further operation can be performed because the system is already set on the better configuration and so the RCST must disconnected it from satellite system (QoS constraint can not be respected and therefore it is useless to continue the transmission).

C. *MARKOV CHAIN BASED CHANNEL MODEL*

Our first contribution is carried out an analysis on the satellite channel in order to provide a valid tool to predict channel transmission evolution and dynamic. For this purpose, we implemented a Matlab model, allowing us to test the physical layer of DVB-RCS satellite system and to collect data in order to compute the transition state probabilities.

We considered the thermal noise due to temperature, the quantization noise and the background noise due to other communication system as a single input, modelled as zero mean and parametric variance AWGN. Moreover, we considered an attenuation due to free space propagation, path loss, based on Friis's model [3]:

$$PL(d) = 20\log_{10}\left(\frac{4\cdot\pi\cdot d\cdot f_c}{c}\right) \quad (1)$$

where f_c is the carrier frequency, c is the light speed and d is the covered distance. The distance d between a geostationary satellite and a earth terminal placed on equator line is 35.778 Km, however for terminal located on other latitude is necessary add to d a further distance corrective term given for the northern hemisphere by [3]:

$$d_{correction} = 42643.7\cdot\sqrt{1-0.295577\cdot(\cos\phi\cos\delta)} \quad (2)$$

where ϕ is the earth station latitude while δ is the difference between earth terminal longitude and satellite longitude.

Furthermore, in order to take into account average climatic condition, also a rainfall attenuation term is considered in accordance with [3]. This term depends on earth station position (and so by elevation angle), therefore it depends on rain intensity in that particular zone (this information can be obtained from the rain climatic zone maps contained in [3]). Another important dependence is by central frequency: in fact attenuation due to rainfall is more significant for the high frequency (>10 GHz). Further detail can be found in [3].

In order to model the error characteristic of satellite channel (both uplink and downlink), we employed the "Gilbert-Elliot model" ([9],[10]). In according with ([9],[10]), our model is based on two states *Discrete Time Markov Chain* (DTMC) with the state named *Good* and *Bad*: we are in the *Good* state if the received packet is correct while we are in the other state if the packet is wrong. In particular, we model a Markov Chain for each possible transmission configuration. A DTMC is completely defined by its transitions probability matrix and by mean state soujourn time. The transitions probability matrix P is given by:

$$\mathbf{P} = \begin{bmatrix} p_{0,0} & p_{0,1} \\ p_{1,0} & p_{1,1} \end{bmatrix} \quad (3)$$

where $p_{i,j}$ is the probability that the process is in the state j at the time t_n if at the time t_{n-1} it is in the state i. In Fig.4 is schematized the two states based Markov model (we associate the symbol "0" to the *Good* state).

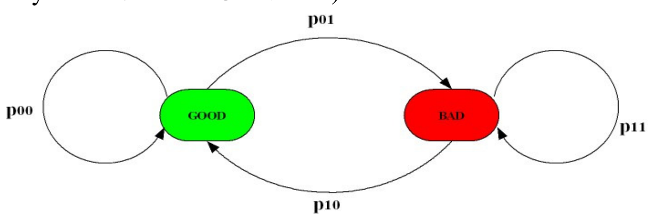

Fig. 4 Two state Markov model.

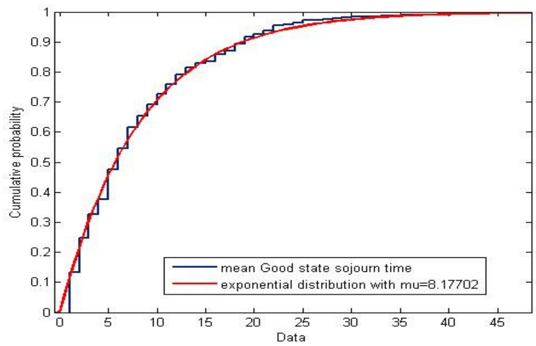

Fig. 5 Mean Good state sojourn time compares with the CDF of an exponential distribution of mu=8.17702.

Satellite channel characterization can be captured by a packet error trace in accordance to [10]. The trace contains information about whether a particular packet was transmitted correctly. The simulations to collect trace have been carried out in critical noise condition to better underline satellite performance. In the following, due to lack of space, only an example, for a specific transmission configuration, of the procedure to compute transition state probabilities and mean state sojourn time will be shown (for the others configurations the procedure is similar).

In this example, we fix the transmission power to 40 dBW, the code rate to ¾ while the employed satellite is OBP. Furthermore we suppose that RCST sender and RCST receiver are located at geographic coordinates of Rome and the both geostationary satellites (BP and OBP) are located at 7° East longitude (such choice is made because at this coordinates are located real satellites). Besides, we consider a total power noise contribution of 30 dB and clear sky climatic condition. Matlab simulations provided us the file trace to analyse. The first step is to evaluate the stationarity propriety of the obtained trace: we define a trace to be *stationary* whenever the error statistics remain relatively constant over time. Using a specific Matlab tool, we verified that obtained trace is a stationary process, so we can proceed to compute transition state probabilities. In our example, we obtain the following values for the **P** matrix:

$$\mathbf{P} = \begin{bmatrix} 0.8781 & 0.1219 \\ 0.8747 & 0.1253 \end{bmatrix} \qquad (4)$$

Finally, the last step is to verify that the mean state sojourn time is exponentially distributed (in fact, in order to affirm that analysed model is a Markov chain it is necessary that mean state sojourn time is exponentially distributed). We test the mean state sojourn time using the *Kolmogorov-Smirnov* test: the result of this test is true if you can reject the hypothesis that the data set is exponentially distributed, or false if you can not reject that hypothesis. In our case, the test return false for both state sojourn time. In particular, for the *Good* state sojourn time, we obtained the *Cumulative Distribution Function* (CDF) plotted in Fig.5: we can see that the data set can be approximated by a exponential distribution with μ=8.17702 as the *Kolmogorov-Smirnov* test confirms.

III. PERFORMANCE EVALUATION

In order to perform the system campaign simulation new software simulator, written in c++ language, has been built. Thanks to this software it is possible to configure all parameters of the system components, as number of source and receiver terminal, RCST number, RCST type, RDBC, VDBC or FCA calls type; moreover other parameters are call average duration per source terminal, average call number per source terminal, type of terminal with different SDR modes. In this last case a terminal can perform SPV algorithm with two type of SDR levels: the first one is with a fixed *Forward Error Correction* (FEC) and a fixed RCST transmission power, while second one is with a terminal having the propriety of changing FEC and transmission power dynamically (see Fig.2). This software simulator respects the DVB-RCS standard so a RCST terminal, for example, if it wants to enter into the system it must negotiate with the NCC component of the system. This phase is most important when a terminal must be switch from a Bent Pipe system to a OBP system. In this case it must disconnect from the BP NCC and connect with the OBP NCC. The protocol for resource reservation that we utilized is RSVP with Integrated Services [11], here a call between a source and a destination starts with a path message from the source; this message travels through the network and it arrives to the destination. When the path message arrives to the destination this terminal responds with a RESV message that has information about the resources that must be allocated long the path by the source RCST , satellite and receiver RCST. In Table I we present the parameters that are utilized in the different simulation scenarios. We utilized an SDR system in which the RCST terminals have the properties of the SDR, and also we utilized a non-SDR system that is equipped with simple RCST terminals, which do not have the capacity to switch between different configurations.

In order to evaluate system performances some results are presented in this section. The objective of the system is to enhance the overall satellite system performances:in fact if a connection does not satisfy negotiated QoS constraint on the PER, our system does not close connection but it transfers connection from BP satellite to OBP satellite (OBP satellite provides better performance, so the PER decreases and the QoS constraint can be now satisfied).

TABLE I
SIMULATION PARAMETERS

Topology Parameters	Value	
Total RCSTs nodes	5, 10, 20, 30, 40	
Total Terminals nodes	80, 160, 320, 480,640	
Simulator Parameters	Value	
Climatic condition	clear sky	
Avarage calls	4/minute	
Average duration of a single calls	5 minutes	
Satellite System	OBP, BP	
Network Parameters	Value	
Medium Access Protocol	MF-TDMA	
Target Burst Loss Probability (ε)	0.01	
Atomic Channel (Slot)	32 kbit/s	
Return/Forward Channel's Trama	47 ms	
RCST Typology	D (2048 kbit/s)	
Number of user Terminal per RCST	16	
RCSTs position	Rome coordinates	
Satellite Values		
Round Trip Time	BP satellite 540 10^{-3} sec	OBP satellite 270 10^{-3} sec
Satellite longitude	≈7° East	≈7°East
Return Channel's Slots	1400	
Forward Channel's Slots	4000	

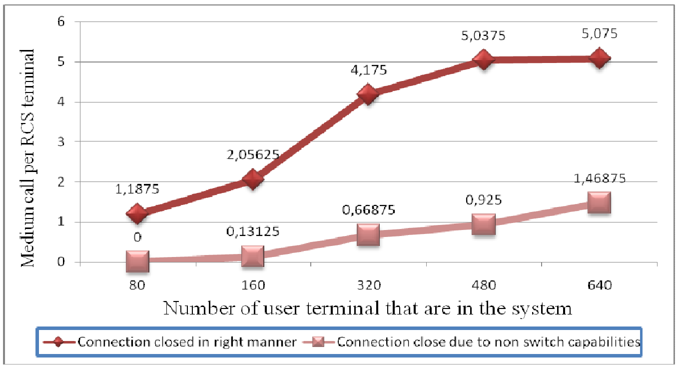

Fig. 6 Right closed call vs. closed call due to no SDR Terminal capabilities.

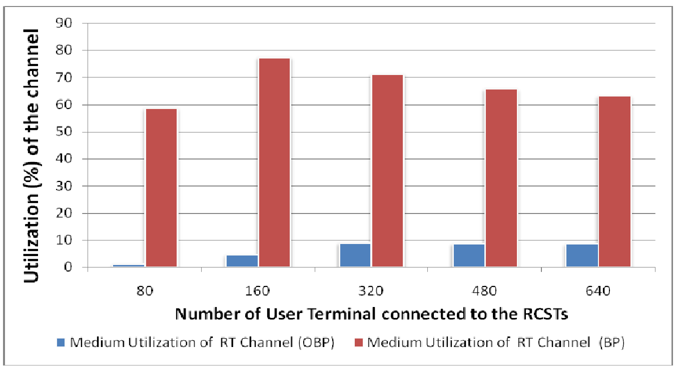

Fig. 7 Utilization of Satellites Return Channel.

In Fig.6 and Fig.7, simulative campaigns want to demonstrate the efficiency of the proposed SDR system in terms of no blocked calls due to the nature of the Bent Pipe Satellite; for this reason all RCSTs terminals starting their sessions connected with the Bent Pipe Satellite.

Fig.6 shows a number of calls that has been terminated in a right manner thanks to the SDR terminal; All the calls that have been initiated have been terminated and it is not truncated due to a violation of QoS constraint; instead also in this figure when the RCST terminal does not have SDR capabilities much more calls are terminated because QoS requirements are not satisfied.

Fig.7 shows the utilization of the Return Channel at the increasing of the number of user terminals connected to the system through the RCSTs. In order to satisfy the QoS requirements some RCSTs switching from Bent Pipe Satellite to OBP satellite; in fact OBP satellite can guarantee better performances and a better S/N ratio with the same channel conditions. This switching, that is possible with the SDR terminals permits to not terminate the active connections.

As shown in Fig.8 and Fig.9 most important delay parameters, like jitter and End-to-End delay do not degrade due to the switching. Only the delay jitter has a peak in terms of max delay due to the time needed to disconnect and connect the RCST terminals with other satellite. However, this time is well spent if no data is lost and furthermore the call can continue with the same requirements that they have been negotiate at the beginning of the call between the source and the receiver.

IV. CONCLUSION

In this work an innovative RCST terminal equipped with SDR technology has been proposed and tested. The RCST has the capability to change via software the transmission chain and moreover it can switch from BP to OBP satellite when QoS requirements are not satisfied. The SDR module is managed by a particular inference algorithm called SPV. This algorithm estimates the channel state through an estimator provided by physical layer; furthermore, in order to model the satellite channel, Markov chain analysis has been carried out starting from exhaustive campaigns on the physical layer in critical noise conditions.. The simulation campaigns have demonstrated that with the use of the SDR technology the number of the calls correctly ending is greater than before. These calls are all the calls that are terminated with the respecting of the QoS requirements. Last two figures shows that the time needed at RCST terminal to reconfigure the transmission chain does not degrade the performances of the system.

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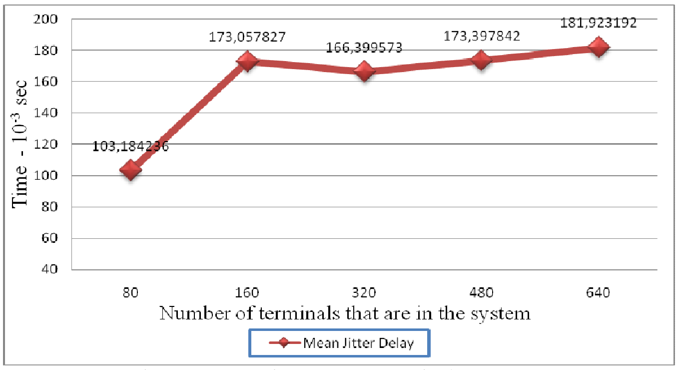

Fig. 8 Average Jitter vs. user terminals augment.

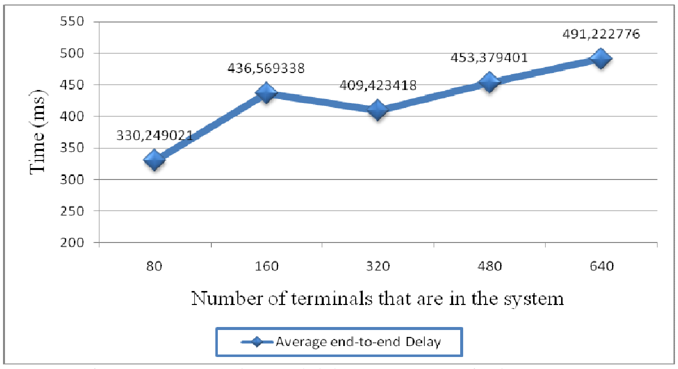

Fig. 9 Average end-to-end delay vs. user terminals augment.

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