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Evaluation of PIM and CBT Multicast Protocols on Fault-Tolerance

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Abstract: In high-speed communication networks, a failure in a multicast node or on a link is often possible. It is especially critical to understand how these failures affect the transmission of real-time applications in convergent data networks. This paper presents the fault-tolerance comparison of multicasting protocols concentrating on Protocol Independent Multicast (PIM) andCore-Based Tree (CBT) Protocols. We investigate the situations in which a copying node fails its multicasting function. A simulation model is developed such a way that faults are dynamically created on nodes and links "for a predetermined period of time." This situation allows us to conceive how stable current multicast protocols are. The number of destination nodes receiving no copies due to faults is compared. The model developed in this paper repeats the simulation for several different size networks from the smallest of a source and two multicast destinations up to a network with a source and 580 different destination nodes. It will be shown that Protocols reactions to the network size are unexpectedly different. This paper presents results of a model of wide area multicast network where faults are introduced dynamically and randomly. Performance metrics in a wide area multicast network are measured and analyzed. The analysis reveals that how PIM protocol outperforms CBT in fault-tolerance for large-size networks in spite of the superiority of CBT in multicasting data under non-failing nodes presented in previous research.

Keywords: Multicast, PIM, CBT , Fault-Tolerance

1. Introduction

The challenge of multicasting data is to minimize the amount of network resources employed by multicasting, and to actually implement multicasting in wide area networks in an efficient way. Wide area multicast transmission requires the use of routers capable of building and managing multicast trees. Multicasting has initiated the development of group communication applications like multi-party conferencing, teleconferencing, multipoint data dissemination, distance learning, and Internet TV.

Various issues and solutions for managing group dynamics and failure handling in QOS multicasting and outline several future research directions are presented in [1]. Researchers propose a multicast routing protocol for fault tolerance and evaluate the performance of nodes with failures in [2]. Multicast protocol for the Internet that supports QoS-sensitive routing, and minimizes the importance of a prior configuration decisions are presented in [3]. OPNET modeling tool is widely used in this paper. Some of the performance parameters evaluated in this paper are end-to-end delay, network source usage, percentage of bits contained in overhead message, and traffic concentration metric for non real-time applications.

The activities in multicast techniques for several multicast transport protocols are surveyed in [4]. This paper presents taxonomy to classify the surveyed protocols according to several distinct features, discusses the rationale behind the protocol's design decisions, and presents some current research issues in multicast protocol design. A tutorial about various multicast routing algorithms and their relationship to multicast routing protocols is discussed in [5]. Implementing multicasting on a wide-area switched network is a challenge since WANs are designed to mainly support point-to-point communications in [6]. Several multicast applications exist, but the implementations are not necessarily. Therefore, as the authors propose, further research is needed reliable multicast transport techniques.

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Multicasting is one of the few technologies without which a certain class of applications in data networks will be almost infeasible on the next generation Internet. It is necessary to focus on the issue of fault tolerance in multicasting. During the lifetime of multicast session, if any node or link supporting the multicast session fails, service will be disrupted. This requires mechanisms to detect node and link failure and to reconfigure the multicast tree around the faulty networks.

Wang and Hou also agree that further research in multicasting in WANs is needed. Performance related constraints of the network due to multicast routing in large-scale networks are disused in [7]. Some of the performance parameters of interest are end-to-end delay, minimum bandwidth available, and maximum packet loss probability. These performance parameters become very important when we begin talking about fault tolerance in multicast networks.

The commercial development of the Internet has brought an enormous increase on its traffic. A few recent services provided over the Internet like video conferencing, broadcasting of news, events, financial information and real-time data requires high bandwidth, they also increase the traffic in the network tremendously. Multicasting reduces the escalation of data traffic because it requires the transmission of a unique packet by the source and replicates this packet only if necessary. Failure in multicasting nodes can have an adverse effect on today's society. Therefore, multicast protocols must be equipped with mechanisms to survive or detect from link/node failure [1].

2. Functions of Multicast Protocols

To accomplish the goal of implementing IP multicasting, three protocols work hand in hand. The first protocol is Internet Group Management Protocol (IGMP); the second protocol is Multicast Interior Gateway Protocol (MIGP), which has different variations or algorithms depending on the network characteristics where it is being deployed. The third protocol is Border Gateway Multicast Protocol (BGMP).

IGMP manages dynamic group membership in a multicast group. Hosts join multicast groups by using IGMP. MIGP is the routing protocol used for multicasting in IP. Different routing protocols exist that may be used depending on the network. The protocols that are mostly used in multicasting are: Distance Vector Multicast Routing Protocol (DVMRP), Multicast Extension of Open Shortest Path First (MOSPF), Core-Based Tree (CBT), and Protocol Independent Multicast (PIM).

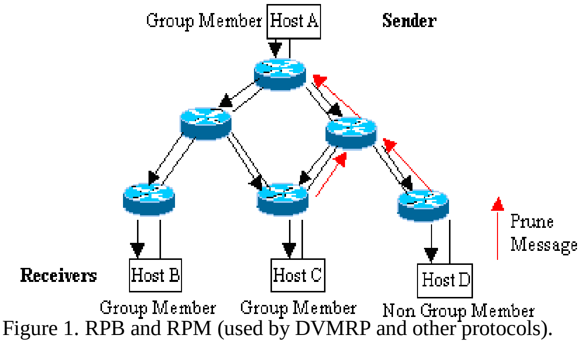

Figure 1. RPB and RPM (used by DVMRP and other protocols).

DVMRP is based on the exchange of routing table information with directly connected neighbors (router to router). Each router using DVMRP maintains information about all the destinations within the system. DVMRP is based on flooding employing a mechanism called reverse path multicast (RPM), a variation of reverse path broadcast (RPB) as seen in Figure 1.

MOSPF is based on the unicast model of OSPF, which is a link-state routing algorithm. Once a link-state table is created, the router calculates the shortest path to each multicast member by using the *Dijkstra's* algorithm [8].

To evaluate the performance of multicast protocols many efforts have been put into defining multicast metrics. The authors in [9] defines the performance metric for evaluation of multicast protocols DVMRP, MOSPF,PIMSM, PIM-DM and CBT and also outlines the simulation parameters and different methods to evaluate the performance of protocol. Expected performance of each protocol is defined according to the different design features of routing protocols.

CBT is an alternative to DVMRP in large networks. DVMRP is costly since it broadcasts packets and could become overwhelming for the router to keep track of every source-group pair. CBT emanates from a single node (core tree) to other routers, forming a shortest path between router and core. CBT reduces storing capacity from every active source-group pair to every active group. Since CBT has a single delivery tree for each group, it results in traffic concentration on a single link. CBT is suited for large number of lower-rate sources that are spread over a large geographical area.

The performance evaluation of two Source Specific Multicast (SSM) protocols for IP networks: Protocol Independent Multicast (PIM) SSM and Lightweight PIM (LPIM) presented in [10]. Also, simulation of a set of wireless ad hoc multicast protocols such as On-Demand Multicast Routing Protocol (ODMRP), Multicast Ad-hoc On-Demand Distance Vector (MAODV), Multicast Open Shortest Path First (MOSPF), and PIM is evaluated under various network scenarios using QUALNET [11]. The modifications to CBT multicast routing protocol for selecting a set of optimal routers in a domain as core routers for a multicast group are presented in [12]. Depending on how the routes connect the multicast members with each other, we can basically distinguish two major categories of protocols [13, 14]: mesh-based and tree-based protocols [15].

Protocol independent multicasting (PIM) is an alternative to CBT. PIM avoids overhead of broadcast packets and supports quality distribution trees for heterogeneous applications. PIM is divided into two categories Dense Mode PIM (DM PIM) and Sparse Mode PIM (SP PIM). DM PIM is similar to DVMRP. Our discussion will focus on SP PIM, which is suitable for wide area networks. In SP PIM, routers explicitly join and leave the multicast group using PIM protocol messages known as Join and Prune messages. These Join and Prune messages are sent to a *rendezvous point (RP)* or rendezvous router that is assigned to each multicast group. RP is selected with the agreement of all the routers in a multicast group. A more detailed explanation of SP PIM can be observed in Figure 2, where only one receiver was used for clarity. Join and Prune messages to RP are used to build a multicast-forwarding tree.

The multicast tree constructed in SP PIM may be of two types; shared tree, which may be used by all senders, and a source-specific tree, which may be used only by a specific sending host. The normal mode of operation of SP PIM creates a shared tree first, followed by one or more source-specific trees if there is enough traffic demand. PIM operation can be seen in Figure 2 where routers join a shared tree and then source specific trees are created within the group routers.

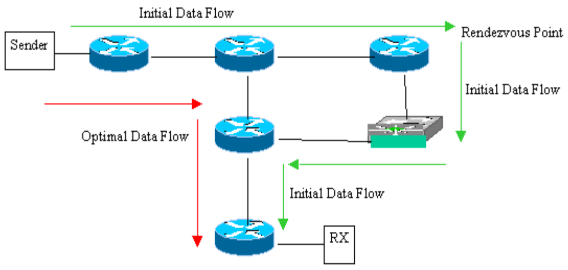

Figure 2. Sparse Mode PIM.

All of SP PIM's mechanism for building and maintaining trees depend on whatever existing unicast routing table is used in the domain (or any given network). The construction of trees is determined by the paths that join messages follow, which is determined by the choice of shortest paths made by unicast routing. Therefore this makes PIM "unicast routing protocol independent," compared to other multicast routing protocols derived from either link-state (MOSPF) or distance-vector (DVMRP) routing [8]. Due to its shared tree building, SP PIM scales well (to a large network), because it reduces the total state in routers to be on the order of the number of groups rather than the number of senders times the number of groups, as in source-specific trees [3]. Also, it compares the performance of PIM (protocol independent multicasting) and CBT (core-base tree) protocols. The main disadvantage of the CBT according to the authors is the saturation of the core due to too many members.

The third protocol required for IP multicasting is BGMP. Border routers use BGMP in order to facilitate communication between different Autonomous Systems (AS) or between different hierarchical areas.

3. Models of Fault-Tolerant Multicasting

The simulation of fault-tolerance for multicast protocols is set up with OPNET simulation tools. With OPNET, a process is an instance of a process model and operates within one module. Initially, a process model contains only one process, this is referred to as ``the root process". However, a process can create additional ``child processes" dynamically, which can create additional processes themselves. This is well suited to model various routing protocols.

Processes respond to interrupts. These interrupts indicate that events of interest have occurred like the arrival of a message or the expiration of a timer. An interrupted process takes actions in response to interrupts and then blocks, waiting for a new interrupt. It may also invoke another process and its execution is suspended until the invoked process blocks. Finite state machines, named State Transition Diagrams (STDs), represent the process models. Finite State Machines are entered using the Process Editor. The states that the process could be in, and the transitions between the different states, can be entered graphically by using a state transition diagram. While the functions to be carried out, variable declarations, macros and constants can be entered using the various 'blocks', such as the state variable block, temporary variable block, header block, etc.

The states can be of two types: forced states and unforced states. In a forced state, the process retains control of the simulation until it has completed all its tasks and is passed to an unforced state, while an unforced state can be interrupted by another event at any time. Similarly there are two types of transition - a conditional transition and a default transition. A transition becomes conditional if: the condition attribute is set by entering a Boolean condition, which causes a transition if a packet is found in the input stream. A default transition is created if no condition attribute is entered, and chosen if none of the other transitions are true.

Much of the performance evaluation work done so far, has been of an analytical and qualitative approach. As of today, very little work has been done on failure recovery in multicast communications [1]. This lack of simulated-based works is highly due to the fact that multicasting protocol applications for wide area networks just started gaining momentum two or three years ago.

An example of a multicast tree with fault presented in its structure is given in Figure 3. The circles indicate the nodes (or routers) in the network, the lines are the links and the red X's indicate that there is a failure at that link or node. The effects that these dynamic failures have in the overall network – using PIM and CBT multicast routing protocols- are studied in this paper.

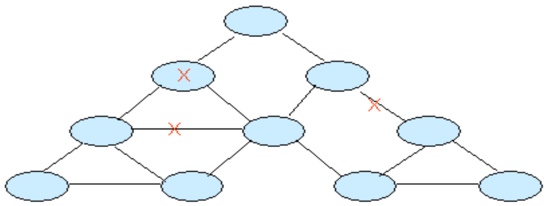

Figure 3. Multicast tree with node and link failures.

Figure 4 depicts a comparison of PIM and CBT on the number of destination nodes receiving no copies. The model developed for this study repeats the simulation for several different size networks from the smallest of a source and two multicast destinations up to a network with a source and 580 different destination nodes.

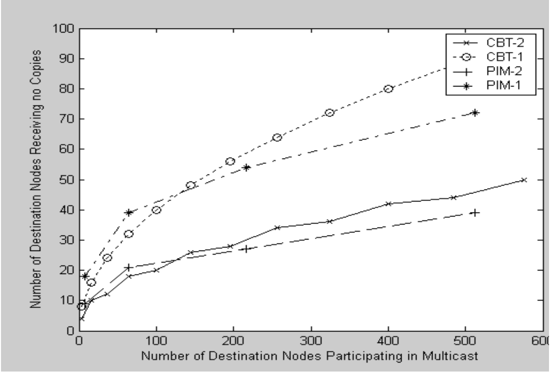

Figure 4. Comparison of multicast protocols on the number of destination nodes receiving no copies in the first attempt.

Figure 5 clearly shows that that PIM outperforms CBT especially when the network size increases. In this graph, two plots for each protocol are contrasted with each other. PIM-1 and PIM-2 plots are respectively referring to the performance of PIM at the very first layer above the destination layers and the second layer above the destination layer in multicast hierarchies.

The same situation can be similarly defined for CBT-1 and CBT-2. The simulation is programmed such a way that the faults are dynamically created on nodes and links "for a given period of time".

This fault-existing time varies from one millisecond to 10 mille-seconds. This means that a fault exists in a network for a limited time. This situation allows us to figure out how stable the multicast protocol is.

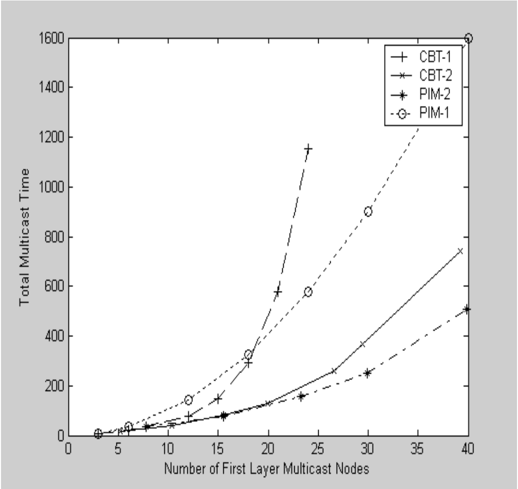

Figure 5. Comparison of total maximum time (in millisecond) required for the completion of multicast function.

Figure 5 presents a different angle of the performance comparison between the two multicast protocols. These plots show the total time (in millisecond) that is required to implement the multicast function. The size of the network under evaluation is the same as the ones presented in Figure 6, but we are showing specifically the number of first layer nodes above the destination layer responsible for making copies. It can be noticed CBT-1 performs better than PIM-1 up to the point that number of nodes turn into 17. Beyond this point, the superiority of PIM becomes significant.

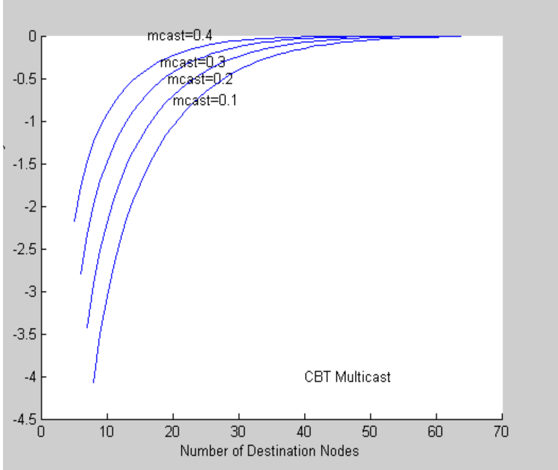

Figure 6. Performance of CBT multicast Protocol on the probability of multicast failure (log based).

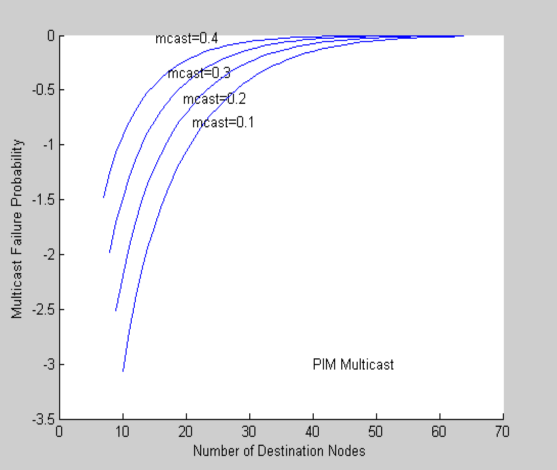

Figure 7. Performance of PIM multicast Protocol on the probability of multicast failure (log based).

In Figures 6 and 7, CBT and PIM protocols are evaluated on the probability of multicast failure (log based) respectively when the number of destination nodes varies up to 70 nodes. This study shows that if the percentage of destination nodes receiving a copy of the message varies from mcast =10% to 40%, the probability of the multicast malfunctioning increases as expected. But what is worth noticing is that for the case that the number of destination nodes are smaller such as 5, 7 or 10, PIM slightly perform better that CBT and this fact is opposite with the number of destination nodes is higher though the latter one is not quite easy to observe from the plots but it can be investigated from the raw numbers out of simulation. This behavior verifies our previous set of results explained before.

4. Conclusion

The recent advancements in high-speed networks are driving the need for efficient fault-tolerant multicast communication services. Our performance evaluation in this paper has revealed how previously discovered parameters, like end-to-end delay, in the benchmark data network change when dynamic failures introduced to both a PIM supported multicast network and a CBT supported multicast network.

The issue that has widely been addressed in this paper was that the performance of multicast protocols to faults does depend on the size of the network. Findings of this paper can especially be taken into consideration when highly delay-sensitive real-time applications like voice and video are intended for transmission.

A comparison of PIM and CBT on the number of destination nodes receiving no copies was presented. The model developed for this study repeated the simulation for several different size networks from the smallest of a source and two multicast destinations up to a network with a source and 580 different destination nodes. It was shown that PIM unexpectedly outperformed CBT when the network size increased. The simulation was programmed such a way that the faults were dynamically created on nodes and links “for a given period of time”. This situation allowed us to figure out how stable the multicast protocol was.

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