RESEARCH REPORT

Use of Application-based Routing for Audio/Video Data in WAN compared to IP Multicast

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Abstract

IP Multicast, which was first developed in 1979, was until recently the state of the art for efficient Audio-/Video (A/V) data transfer to multiple hosts. Despite its efficiency, this protocol is rarely used in the Internet. Reasons include the lack of built-in security, billing and accounting. To be viable, every Router must support these features. „Application Layer Routing“ (ALR), specifically the Multicast extension „Application Layer Multicast“ (ALM), offers an new approach for the efficient transfer of A/V data. In ALR, every included host can act as a router and forward data to another participating host in the network. ALM creates an Overlay Network independent of the Network Layer. This overlay is used for data transport and replication. In this thesis, a comparison study is made between the ALM protocol *NARAD* and IP-Mulitcast, by simulating a Waxman topology in Opnet. The degree of the links in these topologies varies in each scenario studied. By examining the efficiency of each protocol in simulation, the study concludes whether ALM is a viable alternative to IP-Multicast.

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Chapter 1

Introduction

Since 1962, the requirments on the internet and it's services changed completely. In the beginning, the ARPANet was a small network only a for University's in the US. With the proceeding development of this Wide Area Network (WAN), more and more organizations and private institution's joined. The deployment of Email and HTML brought the break through in the public sector. Only in the last twelve years, the number of users grew over 500%. Today, most of the people use the internet every day for, Email, Facebook, Twitter, Youtube, Netflix etc.. This cause a growing consumption of bandwith in the WAN. The network of the networks is not only used for Websites and Email, more and more provider offer IP-TV, Video on demand (VoD), Video Conferencing etc. these services require a lot of bandwidth. For example the VoD provide 30% of the complete upstream in the US [2]. The growing bandwidth consumption needs an efficient data transfer to reduce this consumption. IP-Multicast is still state of the art for efficient A/V data transfer. The slow development of this protocol in the internet makes it not suitable for the current requirements. The young technique *application layer routing* can offer similar services like IP-Multicast, but more flexible.

Chapter 2

IP-Multicast

IP-Multicast and it's *Multicast routing protocols* (MRP) are based on the development from Steve Deering in 1979. Until today a couple of MRP has been published. All of them act in a similar way, they only difference is the routing algorithm. [3]
IP Multicast has several drawbacks that have so far prevented the service from being widely deployed. It offers minimal functionality such as error, congestion, and flow control; but a best effort data transfer. Also IP Multicast need routers in the network which all provide the mulicast functionality. This add's more complexity to the network and it's devices. Every router in a multicast group sends one packet to the next router in the Group. The device next to the end host replicates the packet. No duplicated packet will be send over an link. [3]
Until today IP-Multicast is not wide spread in the internet environment. Internet service providers (ISP) don't want to bring additional knowledge and complexity in their networks. Also no management and security features have been added to the protocol since it has been developed. No billing and account system is possible to use with these protocol. It also don't correlate with the standard business model of the ISP's. [4]

The unreliable transport portocol is used for all multicast protocols. It is only unidirectional and has no congestion- and folw control. There is no mechanism to handle packet loss, like reducing the data rate. It would also very complex to adjust the data rate for several clients. MRP are used in the *MBONE* an of approx. 3000 networks, which are able to exchange multicast data packages. The protocol overhead is $\approx 7\mathtt{mbps}$. [5] But there have not been any test's in the internet infrastructure for big IP-multicast services. In small networks like LAN is the use of multicast suitable, where no management is needed and it can easily controlled. All the published MRP can be categorized in two groups. The mode of operation and the deployment are the reasons for the categories:

2.1 Dense mode

Dense mode protocols are designed in the assumption that most of the routers are part of an multicast group and the network has high bandwidth capacity. E.g. LAN or campus networks. The network will periodically flooded to find and optimize the optimal path for multicast. This periodical message will be send in every connected subnet. Router which have no mulicast clients have to send explicit messages to unsubscribe from the service. The information out of this flooding is used for refining the *spanning tree* and therefor the routing. Protocols with the dense mode technique:

- Distance Vector Multicast Routing Protocol (DVMRP)
- Multicast Open Shortest Path First (MOSPF)
- Protocol-Independent Multicast - Dense Mode (PIM-DM)

2.2 Spares mode

Spares mode protocols are designed in the assumption that less bandwidth is available in the network and less routers are part of the transmission. In the beginning, the tree is empty. Every node which want to be part of the session has to send an join message to an rendezvous point (RP). This message activates on the path to the RP multicast on every router. This path will also bee the multicast path for the whole time, and it won't be changed. No flooding or refining mechanism will be used. Spares mode protocols are:

- Core Based Trees (CBT)
- Protocol-Independetn Multicast -Spares Mode (PIM-SM)

2.3 Distance vector multicast routing protocol

This protocol is defined in the RFC 1075 and was developed in the free *mrouted*. Its one of the first IP-multicast protocols. It's based on the unicast distance vector routing protocol *RIP*, only with an multicast extension. [3]
Routers with the Distance vector multicast routing protocol exchanges the information about the group membership and the costs for the transport with its neighbors. Each tuple, consting (Group,Source) is swapped by the router with the forwarding tree. The communication between the layer three devices is based on *IGMP*. Every status information message, like the group membership is exchange with the use of this protocol. [3]
If an router receives an multicast datagram, then the forwarding tree will be checked and a copy of the datagram will be send out in the right interface. [3]

Chapter 3

Application Layer Routing

Application Layer Routing and it's multicast extension *Application Layer Multicast*, are very young techniques. No institution or committee has standardized any ALR/ALM protocol. But a few products still use this mode of operation for it's services. For example Skype is using this technology for his Audio- Video-Chat. It covers the most of the weaknesses of IP multicast, like security and management. Is a pure software product, so almost every feature can be added to the service. Cause it's made out of software, it don't have any hardware requirements on the network. It's can use the internet infrastructure to span the overlay network or any other network or topologie. It is completely independent from the underlining network and it's devices

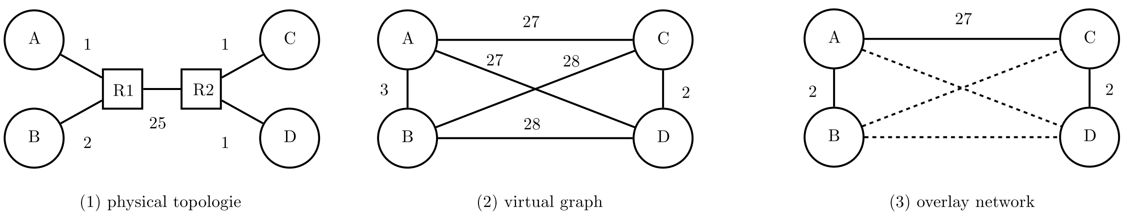

Figure 3.1: Pysical vs. overlay topologie

The many difference between IP-Muticast and ALR is the OSI layer on which the routing decision will be made. Standard unicast Routing is done on the network layer. ALR make their decisions on the OSI layer seven.
Every client which is included in the ALR architecture can act's as an router. Trough these nodes an completely independent network will be created. These network will be called *overlay network*. Overlay networks are not influenced from the OSI layer tree, an can be seen transparent. Figure 3.1 shows the difference between the physical network (figure 3.1(1)) and the overlay network (figure 3.1(3)). The virtual graph span's all possible virtual connections between the Osi 7 devices. Out of these graph the optimal connection for the Application Layer routing will be chosen.
In ALR acts in two different modes. It's based at what level the protocol is expected to be deployed: The *infrastructure level* or the *end system level*. [6] [7]

3.1 Infrastructure level

On the infrastructure level, one or more *proxy server* are used, to organize the overlay network for the end users (Figure 3.2(2)). Every client is connected to one of these servers. All the A/V data will be provided form the Proxy Server. The client itself don't forward data to any of the other end systems. Thereby the a greater bandwidth can be amused form the proxy nodes. Also a longer life cycle of the overlay nodes can be expected. No node which sends data is transient, like in the end system level. [8]

3.2 End system level

End System Level ALM protocols expect the participation of the end host's for data forwarding. All clients organize themselves into an overlay network. Based on the algorithm each end host, forwards it's revived A/V data to the „next“ client. Figure 3.2 outlines the difference between the two protocols. In the end system approach, the the load of the multicast session will be shared over the internet infrastructure. It highly depends on the upload bandwidth the clients can offer. One the other hand, in the infrastructure only the proxy server need a high bandwidth capacity, it is completely independent form the end host's.
The choice between this two approaches is more driven by the business model than form the technology. [8]

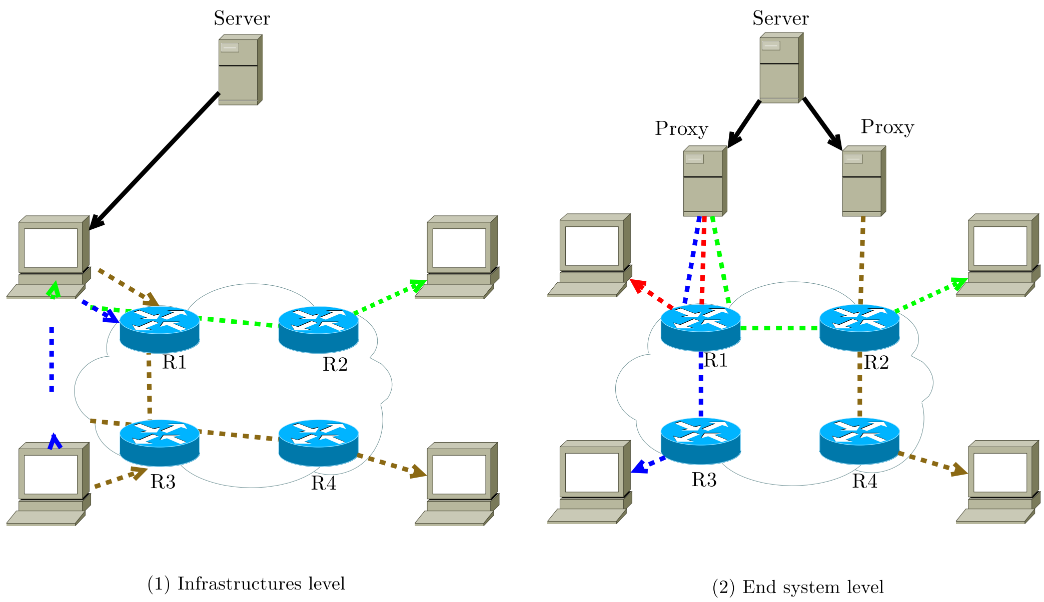

Figure 3.2: End system level versus infrastructure level

3.3 Narada

The ALM protocol wich was used for this study *NARADA*, was developed by „Carnefie Mellon School of Computer Sience“. It's one of the first application layer multicast protocols. The *application domain* for the protocol is for less members, the main metrica are bandwidth and latency. [9] The registration of the clients with the multicast group occours at an *rendezvous point* (RP). These answers the registration process, with a list of all clients in the overly network. Out of this list the client chooses its „neighbours“ randomly by itself, an establish an connection with them. The *deployment level* is as the *ebd system level* defined (see 3). [9] Status information are exchange periodically between all clients. Each node as the knowledge of all clients and their status in the network. If one node drops out as an neighbor, the client chooses another node out of the list. [9] In „A case for end system multicast“ the control overhead is defined as $O(N^2)$ [6]. The *reverse path forwarding* technique, which is known form IP multicast to define paths in the overlay. An easy heuristic decides whether a path stays alive or it will be failed [6].

Chapter 4

Simulation

The main goal of the simulation is, to answer the following question:

How efficent is application layer routing compared to IP-Multicast for Audio Video transmissions in WAN

To answer this question several small questions have to be included:

- Which effect, does the change of the mesh degree has
- How is the behavior of the end to end delay
- How is the behavior of the throughput
- How is the behavior of the stress level

This work is based on the results of Yang-ha Chu, Sanjay G. Rao, et al. in „A case for end system multicast". In these work a comparison between the Narada protocol and Distance vector multicast routing protocol was done with simulations and internet experiments. Yang-ha Chu, et. al. vary the group size in the simulation an measured the degree of utilization. The mesh degree was never changed during

their simulations.
The studies of Matthew Doar and Ian Leslie in „How bad is Multicast" has shown, that a change of the mesh degree has an impact of an IP-Multicast transmission. Figure 4.1 out of „How bad is Multicast" shows the influence of mesh degree to the efficiency of the protocol. An analysis of application layer routing refereeing to the mesh degree has not been done.

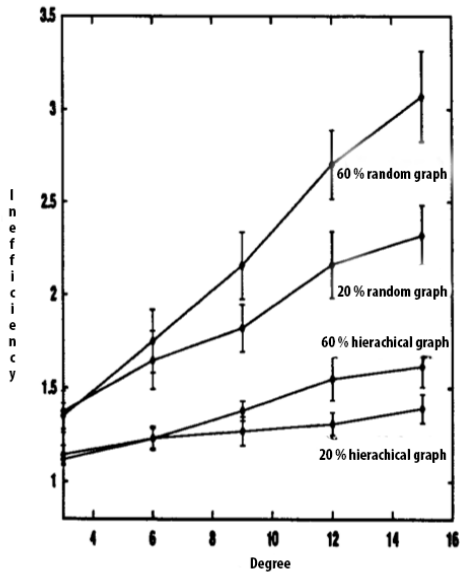

Figure 4.1: Inefficiency of IP-Multicast against mesh degree [1]

4.1 Simulation Architecture

Based on the topologie and the protocols of „A case for end system multicast„some simulations will be done in Opnet©, to examine the behavior against the mesh degree. For these simulation the „Georiga Tech. random graph generator„was used to create the topolgie. The generator was also used by Yang-ha Chu, Sanjay G. Rao, et al. The createt topolgies had been transferd into Opnet©. For application layer multicast the *NARADA* protocol was used and for IP-Multicast *DVMRP*. All setting's like in „A case for end system multicast" and comparable with this work.

Waxman Random topolgies are often used to model internetworks like an WAN. Simple random topolgies with an fix probability p are not able to reproduce the internet environment [10].
The most used method to model such an network is the Waxman algorithm. Every edge has an own probability produced with an function. A connection from u to v, an edge and described by [11]:

$$P(u, v) = \alpha e^{\frac{-d}{\beta L}} \tag{4.1}$$

The euclid distance between u to v is d. L is defined as the maximum distance between two nodes. And $a < \alpha, \beta \leqslant 1$ [11].

4.2 Implementation

For the simulation in Opnet©, models the propagation delay based on the length of the link. For unicast routing the shortest delay is used on the physical link. During the simulation no background traffic will be produced. This give the possibility to analyze only the traffic for the Audio/-Video conference and the associated protocols (DVMRP, IGMP, IP, NARADA, etc.). In topologies created with the „Georiga Tech. random graph generator", the degree of the mesh will be varied form 100% to 50%. For each set 1000 test execution will be done. For each metric the mean value will be calculated over all executions. This is done to have statistic secure values.

4.3 Metrics

The main goal is it, to evaluate the performance of the different scenarios and to make them comparable. Like in „A case for end system multicast“ the same techniques will be used, because the whole simulation is based on these simulation model. In each test set the *end to end delay*, the *throughput* is observed. Over these values the mean is calculated to have one value to describe the scenario and makes it easier to compare the results. This is also done by Yang-ha Chu, Sanjay G. Rao, et al. Also the Stress of each scenario is analyzed. Stress is defined by duplicated data packets over one physical link. This metric shows how efficient a protocol works. A stress with the excat value of one is ideal. This means, no link caries any data packet twice. The measurement of packet loos and time until the first packet was not done in this work, cause these values will not be like in the real world. The simulation has an adequate link capacity, so no packet loos was expected. Also UDP is used as transport protocol which do not handle lost data. Deflected form the results out of „A case for end system multicast“, small groupsizes has an more efficient performance than bigger ones. For this reason a size of five Host's was chosen.

4.4 Results

All scenario sets haven been examined with IP-Multicast, NARADA and naive unicast. Unicast was evaluated only for an simple comparison to the other protocols. Each data was captured 15 seconds after the simulation start, to consider the undershoot of the simulation-environment. The evaluated data has been calculated through the statistic module in OPNET©. All the values are in an 95% confidence interval based on the normal distribution. Only the packets for the Audio- /Video Confrence has been analyzed, and they are free form the control overhead.

Stess

Stree in a network is defined by the amount of identical packets transmitted over an physical link. The ideal, Stress = 1, means no duplicates have been on an link. These duplicated packets produce an higher load on a link. This metric shows how efficient a protocol uses an network infrastructure.

Figure 4.2 shows the trend of the Stress of NARADA, DVMRP and unicast against the mesh degree in percent.

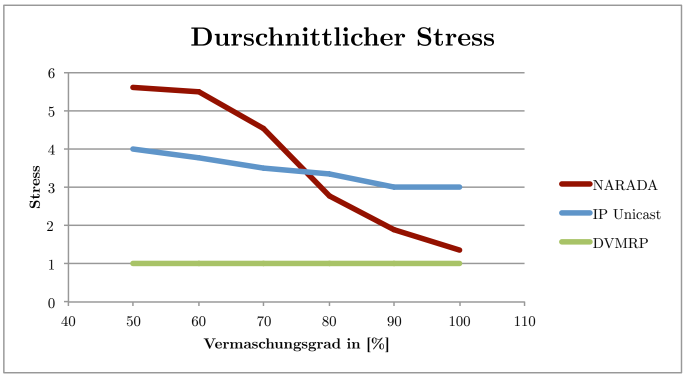

Figure 4.2: Average stress

<u>DVMRP</u>

IP-Multicast with it's packet replication on the router level, has in each simulation the stress value of one (compare table 4.1). This efficient technique is uninfluenced by the mesh of the degree.

NARADA

With an higher level of the mesh degree the stress declines. The use of the overlay network don't care about the underlining IP network. Thereby physical links are more often used for data transitions. The decline of the degree the amount of links between the routers also decline and the flows have to use less links. Through this change of the network the stress level increases. The trend line out of figure 4.2 is ($y = 0,0001x^3 - 0,0232x^2 + 1,6148x - 29,84$) and for unicast ($y = -0,0213x + 5,03$). The intersection of this two functions is in 71,9%. This means, a higher degree than 72% has an lower stress then IP-unicast. The degree of the mesh has an huge influence on the stress. Overall simulation an increase on more than 75% can be identified (compare table 4.2). But an perfect stress with value one has in none simulation been reached. An mean value with 1,35 is an very close on the ideal stress.

Unicast

Naive unicast has an similar trend, like NARADA but its more flat. By reducing the degree at 50%, the stress level is reduced by one. At no time it was less than tree. In unicast there is no packet replication at any point. Every data is transmitted from the source to each sender. This is the reason that an value of tree never has been undershoot. An ideal stress level can never been achieved with unicast.

Degree in %	100	90	80	70	60	50
NARADA						
Stress	1,35	1,89	2,75	4,5	5,49	5,6
DVMRP						
Stress	1	1	1	1	1	1
Unicast						
Stress	3	3	3,33	3,5	3,75	4

Table 4.1: Stress in comparison to the protocols

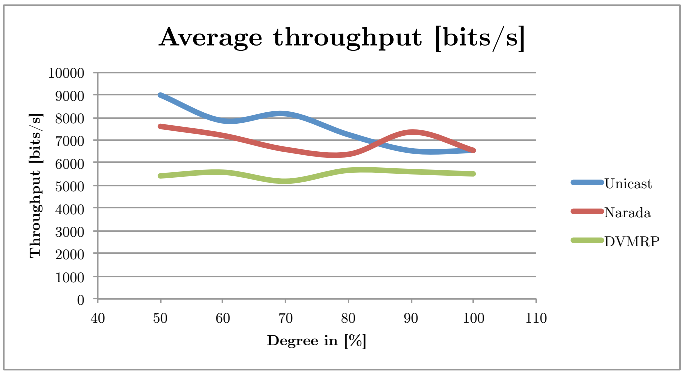

Figure 4.3: Average throughput

Throughput

The measuring of the throughput are base on the mean throughput over all active links, which has been used for the data transmission. The value shows the load of the links. The throughput has a direct correlation with the stress level. If the amount of the duplicated is declining, also a drop of the throughput is to expect. In figure 4.3 the trend of the throughput against the degree is shown. The unit is [bit/s] to see the trend more accurate. DVMRP has an approximately constant throughput. The small changes are based on the simulation accurateness (see table 4.2). This trend comparable to the stress of DVMRP.

For unicast is declining with the rising of the mesh degree. A higher degree splits the load on more links, and the mean load is declining. NARADA has an related to unicast trend, but with 19% lower values. If you compare the values of NARADA

Degree in %	100	90	80	70	60	50
NARADA						
Throughput [bit/s]	6569,05	7353,21	6373,62	6587,65	7202,65	7604,56
DVMRP						
Throughput [bit/s]	5498,36	5610,37	5669,37	5186,37	5584,04	5423,37
Unicast						
Throughput [bit/s]	6530,64	6530,64	7241,96	8162,46	7848,04	8986,09
Difference Unicast-NARADA in %	-0,56	-12,59	11,99	**19,29**	8,22	15,37
Difference MC-NARADA in %	16,30	23,70	11,0 5	21,27	22,47	**28,68**

Table 4.2: Throughput in comparison to the protocols

and multicast in percent (see table 4.2) there are savings up to 28,66% at 50% mesh degree.

End to end delay

End to end delay is the time of a packet on the link from the source to the destination. These time is the sum of the *propagation delay*, *transmission delay* and the *processing time* per link:

$$d_{end-end} = \sum\nolimits_{n=0}^{N} [d_{transmission} + d_{propagation} + d_{processing}] \tag{4.2}$$

For the metric of the end to end delay the mean time of all links has been calculated. This gives the ability to describe the delay in the Network with one value and makes it easy to compare. In table 4.3 you can see an higher delay for IP-multicast, compared to unicast and NARADA. These high delay times for multicast are the result of the higher *processing* time in the routers. Every router interface which is connected to it, is included in the multicast tree. With the rising mesh degree the

Vermaschungsgrad in %	100	90	80	70	60	50
NARADA						
Delay in [s]	0,00786	0,00492	0,00185	0,00162	0,0013	0,00105
DVMRP						
Delay in [s]	0,0167	0,00127	0,00857	0,0789	0,0072	0,0053
Unicast						
Delay in [s]	0,00125	0,00109	0,00121	0,00086	0,00086	0,00087

Table 4.3: Comparison of the protocols

amount of the possible multicast links is also growing. This causes an longer search in the multicast tree for before the forwarding decision takes place. In addtion to the tree, DVMRP also has two routing tables, one for the unicast routing and the second one for the multicast interfaces. All this properties leads to an higher *processing* delay. At an mesh degree of 50% multicast has an factor 6 higher delay compared to unicast. NARADA has an analog trend to unicast, at an mesh degree of aprox. 80%, the delay of NARADA is rising. With more links in the topology, the amount of the used routers in the IP layer is rising. Also more links are used for the data transmission. This leads to an higer *propagation delay*, *transmission delay* and *processing dely*. Overall the end to end delay is rising. Unicast has an straight trend, over all degrees it is constant. The processing for naive routing is such tiny in the simulation environment, the it has no influence on the trend line.

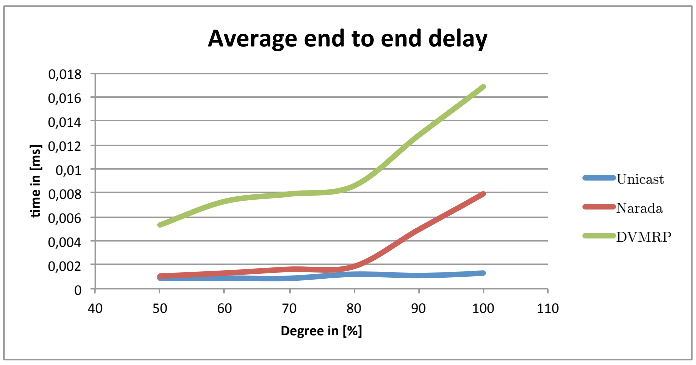

Figure 4.4: Average end to end delay

4.4.1 Summarizing the results

The evaluation of the simulation, shown in table 4.4, indicates that application layer routing can bee seen as an alternative to IP multicast, with an small group size. The network load, and the performance of the application layer multicast protocol NARADA have rarely no differential in the efficiency of the throughput and the delay. WAN have high capacity links, an increase for such an application can easily be handled. Also a lot of unicast application could be replaced by application layer routing. This would save capacity. Overall more bandwidth capacity will be saved with an use of application layer mutlicast. The complex calculation of the multicast tree in the router level, forces an higher cpu load of the routers, this affects an higher processing delay. These delay is much higher than in unicast routing, which application layer routing uses.

Generally the results of these simulation is, that application layer multicast NARADA, has it's highest efficiency on a mesh degree of 72%. With an higher degree the delay is rising, but the stress is falling. If the mesh degree is smaller than 72% the stess level is going bigger, but the delay is falling.

Mesh-degree in [%]	Ø End to End Delay	Std. derivation Delay	Confidenz-intervall 95%	Ø Throughput in [bit/s]	Std. derivation Throughput	Confidenz-intervall 95%	Stress
Narada							
100	0,00786	$1,02 * 10^{-7}$	0,0079 - 0,0079	6569,05	227,42	6467,7- 6670,4	1,35
90	0,00492	$2,03 * 10^{-7}$	0,0049 - 0,0049	7353,21	305,52	7170,3- 7536,2	1,89
80	0,00185	$1,03 * 10^{-7}$	0,0019 - 0,0019	6373,62	253,92	6247,3- 6500	2,75
70	0,00162	$1,30 * 10^{-7}$	0,0016 - 0,0016	6587,65	141,02	6548,7- 6626,6	4,5
60	0,0013	$1,30 * 10^{-7}$	0,0013 - 0,0013	7202,65	240,72	7,0891- 7316,2	5,49
50	0,00105	$3,23 * 10^{-7}$	0,0011 - 0,0011	7604,56	293,34	7435,9- 7773,2	5,6
Distance Vektor Multicast Routing Protocol							
100	0,0167	$1,03 * 10^{-7}$	0.0167 - 0.0167	5498,36	254,72	5371,5 - 5635,2	1
90	0,00127	$1,14 * 10^{-7}$	0.0013 - 0.0013	5610,37	281,04	5455,6 - 5765,2	1
80	0,00857	$1,14 * 10^{-7}$	0.0086 - 0.0086	5669,37	239,72	5556,7 - 5782,0	1
70	0,0789	$1,02 * 10^{-7}$	0.0789 - 0.0789	5186,37	235,63	5077,5 - 5295,2	1
60	0,0072	$1,22 * 10^{-7}$	0.0072 - 0.0072	5584,04	251,74	5459,8 - 5708-2	1
50	0,0053	$1,03 * 10^{-7}$	0.0053 - 0.0053	5423,37	295,53	5252,2 - 5594,5	1
Unicast							
100	0,00125	$1,03 * 10^{-7}$	0,0013 - 0,0013	6530,64	260,47	6397,7 - 6663,6	3
90	0,00109	$1,99 * 10^{-7}$	0,0011 - 0,0011	6530,64	259,84	6398,3 - 6663,0	3
80	0,00121	$1,67 * 10^{-7}$	0,0012 - 0,0012	7241,96	240,50	7128,6 - 7355,3	3,33
70	0,00086	$1,90 * 10^{-7}$	0,000863 - 0,000863	8162,46	310,30	7973,7 - 8351,2	3,5
60	0,00086	$1,03 * 10^{-7}$	0,0008826 - 0,0008826	7848,04	276,06	7698,7 - 7997,4	3,75
50	0,00087	$1,09 * 10^{-7}$	0,0008793 - 0,0008793	8986,09	299,69	8810,1 - 9162,1	4

Table 4.4: Analysis of the simulated data with confidence intervall $\alpha = 0,05$

Chapter 5

Future work

The results of this work represent application layer routing as an alternative technique for transmitting Audio/-Video over the WAN. It has an high efficiency in the network layer, and covers the most weaknesses IP-Multicast has. ALM is very young and this research covers only a part of the protocol. The simulation only covers an part of ALR and not the whole technique. Some further research and work should be be done like:

- **Internet experiments**
  Execution of the current simulation in an real internet environment, to validate the measurements
- **Background traffic**
  Examine the simulation with background traffic, like in real environments
- **Overhead**
  Examine the control overhead of the protocols in an experiment

- **Dynamic changing topolgies**

  WAN are not static topologies like this simulation. In the real world, the topologie is changing dynamically. The behavior of the protocoll should be examined in changing topoiogies

- **Deployment level**

  NARADA uses the „infrastructure“ deployment level, other protocols which are using the „End system level“ should be examined

- **Protocols**

  Research of other application layer multicast protocols

- **Opnet**

  Research of the correct multicast behavior concerning to the delay.

Chapter 6

Inovation

The young techniqe*Application Layer Routing* with the multicast extension *Application Layer Mulicast* offers an easy, cheap and efficient way for transmitting data through the internet. But it's more than just data transmitting: from adding additional security features like AAA (Authentication Authorization Accounting) to converting messages during the routing process.

All state of the art data transmission is based on ISO/OSI layer three decisions, like the mode of operation of IP-Mulitcast. It's efficent but need's the implantation in the router level. *Application Layer Routing* is implemented in the host's, on the ISO/OSI Layer seven and a pure software product. It don't need any specific hardware requirements or protocols. The provide can define after his own conceptions. There are no rules or limitation in the implementation of the protocol. These can be defined after the requirements. Also geographically there are no limitations, like ISP networks. It can be easily spread all over the internet. It can be use for almost every data transition and can dissolute several known techniques.

Smart Grid

Smart metering and Smart grid got a lot attention in the last month. Until know it's not clarified how the data should be transferred. ALR offers an possibility to aggregate and encrypt the data on the device and send it direct to the provider, through an overlay network. These network can been seen isolated and secure, based on the internet infrastructure.

In addition, the messages can be transformed during the transmission form one format to the other. Different „Smart meter Protocols"based on the vendor can be used, and the devices can interact.

Next generation networks

Mobile network providers follow the trend of developing the „Next generation network"where every services can be accessed independent from the network access technologies. Also the services can be accessed from everywhere at anytime. Also ALR is independent form the network access technologies, and corresponds with the next generation network concepts. The billing and accounting gateway from the ISP's can be used from ALR-devices, because it's only software. Existing API's can be used by almost everybody.

The naming principles of ALR could also be used for the voice and text conversation, like for VOIP, which should be used in the next generation networks.

Application Layer Routing can be seen as **the new generation of routing**, based on the existing environment. Every service provider can build it's own overlay network for it's service, without spending lot of money for hardware. They can also implement ALR easy in its business modell. The less cost's makes it easy for small startUp's to rapidly create and deploy its services over the internet.

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