Interactive Internet Television for Mobile Devices and Large-scale Areas

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***Abstract*—In coming years it is supposed that importance of the Internet television technology will grow and also number of households and subscribers paying for this service will be increasing. It is also supposed that this technology will enable a new kind of services, where one of them is an interaction of customers with content provider. For this purpose a method of hierarchical aggregation for a feedback transmission has been proposed, which is in comparison to classical real-time control protocol quite scalable. This paper describes integration of hierarchical aggregation with internet coordinate systems, which can make communication between session members more efficient. It also describes some advantages of this integration and a prototype of such system is introduced. Furthermore, it describes some use examples and options for extensions of such architecture.**

***Index Terms*—Quality of Service, Global network positioning, Real-time control protocol, Real-time protocol, Hierarchical aggregation**

I. Introduction

The Internet Protocol TeleVision (IPTV) market has achieved a great attention in recent years. According to several independent market analyses, IPTV technology will soon take a significant additional market share among China, Europe, USA and even other areas. IPTV will enable a new kind of services such as interactive TV. However, to be really interactive, there is need to transmit all the user action in some limited time period and this could become a problem. Consider an example where we have IPTV session with two million of subscribers. When all the subscribers decide to vote for some kind of poll, this would lead for ten millions times sending a message of at least 64 bytes (assuming a presence of User Datagram protocol (UDP) header, a packet header to distinguish it from standard Real-time Transport Protocol / Real-time Control Protocol (RTP/RTCP) header and, also, there can be not even simple YES/NO votes), this would lead to need to transmit about 600 MB. A general view of the term *interactive TV* is a communication between content provider and subscribers, where the content provider announces some poll and waits for some time for answers from subscribers. We are in this work motivated not by a need to enable just simple request/reply model, where also simple HTTP protocol based approaches can work sufficiently. We are in this work motivated by a vision to enable conveying of subscriber actions continuously during entire TV program time, from . In such cases especially for a bigger numbers of receivers it will pay of to provide optimized and relatively well scalable backchannel technology. In the opposite case it may arise some traffic peaks, which potentially may cause loss of votes, harm other already running services on the network or even the IPTV broadcasting itself. One of the promising technologies for this purpose is so-called hierarchical aggregation (HA) [3], [4], [5], [13], [14].

This paper describes how the hierarchical aggregation (HA) can be integrated with coordinate systems to save bandwidth and proposes a real architecture for IPTV systems. HA is inspired by principle often utilized by wireless sensor networks (WSN) and it is used to gather huge amount of data in a short amount of time. However in WSN, there is emphasis on energy efficiency. In the field of the Internet there less need to take emphasis on the energy consumption. However compared with WSN, there is need to take a better emphasis on complex Internet topology.

The integration of internet coordinating systems with HA can make communication even more effective and it can enable not only simple interaction as a question/response in some kind of polling, but even continuous connection of subscribers with content provider and convey their opinion during entire time of the session. It is also scalable enough for any further growth of number of receivers in the session and even mobile devices in future.

What should be emphasized here, this paper does not deal with security issues. The securing the communication can be often simplified by the identification of paying subscribers and can significantly vary from case to case.

The first part of this paper is involved in RTP/RTCP protocols defined in RFC 3550 [17] specification and its mathematical foundation. It also gives a brief overview of the HA. The next section describes internet coordinate systems and gives a brief comparison of these algorithms concerning HA. The following section proposes an architecture for integration of HA with selected coordinate system. The last section describes how it could be further extended to estimate positions of subscribers.

II. Introduction to Real-time Protocol and Hierarchical Aggregation

RTP and RTCP [1] are protocols designed for data delivery in real-time and, among other things, to measure the quality of service (QoS). This couple of protocols is today used for almost all transmission of time sensitive data such as audio, video, subtitles, etc. This is the reason why the paper will describe RTCP protocol rather than IPTV service.

The RTCP protocol uses receiver reports (RR-RTCP) and sender reports (SR-RTCP), which are sent between sender and receiver and which contain necessary information to evaluate e.g. RTP packet loss, jitter, round trip delay time, etc. In the RTCP protocol, the maximal consumed bandwidth is limited to 5 % of the total session reserved bandwidth. To meet this limitation, the period for transmitting RTCP messages must exactly fulfill the following equations [17]. These equations compute the period for transmitting RR-RTCP messages (T'_{RR}), SR-RTCP messages (T'_{SR}) and RSI-RTCP messages (T_{RSI}). All of them are described by equations (1), (2), (3) and (6). When the number of users is low the period will be evaluated as too short and this will lead to unnecessarily wastage of bandwidth. For this reason the final values of equations T_{RR}, and T_{SR} are limited by their lower bounds by the constant of 5 seconds. Finally the compensation factor C is added; see equations (6), (5), (7) (or see [15], [17] for more detailed information) to take also into consideration empirical experiences and long-term observations.

$$T'_{RR} = \frac{L_{RR} \cdot n}{75\ \% \cdot B_{RTCP}} \quad (1)$$

$$T'_{SR} = \frac{L_{SR}}{25\ \% \cdot B_{RTCP}} \quad (2)$$

$$B_{RTCP} = B \cdot 5\ \% \quad (3)$$

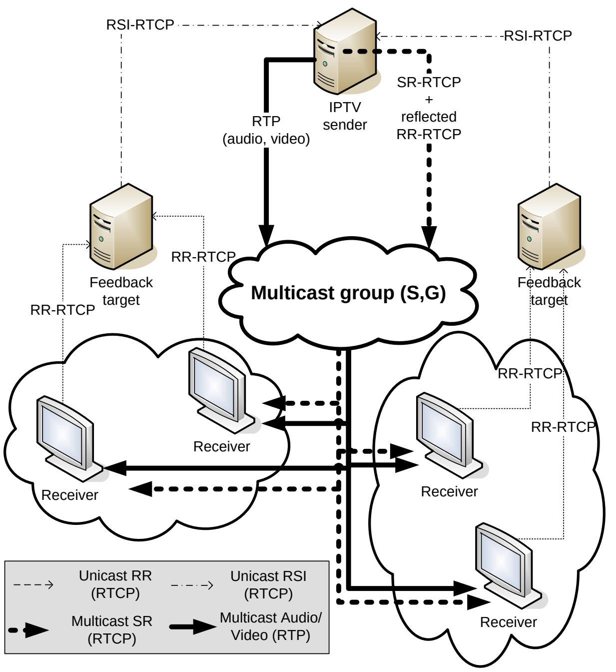

Fig.1. The RFC 3550 RTP/RTCP protocol improved with hierarchical aggregation. RR-RTCP stands for receiver report [17], SR-RTCP stands for sender report [17], RSI-RTCP stands for receiver summary information packet [15]

$$T_{RR} = \frac{\max\,(T'_{RR}; 5\text{ sec})}{C} \quad (4)$$

$$T_{SR} = \frac{\max\,(T'_{SR}; 5\text{ sec})}{C} \quad (5)$$

$$T_{RSI} = 1.5 \cdot T_{SR} \quad (6)$$

$$C = e - 1.5 = 1.21828 \quad (7)$$

L stands for the packet length of a message where its index denotes the packet type, B stands for the total session bandwidth, B_{RTCP} for the bandwidth reserved for RTCP protocol, and n is the total number of receivers in the whole session. As follows from equation (1) and (4), for a large number of receivers n the period T_{RR} can become pretty long and this leads to averaged values from longer time period, which can be useless for some kind of applications, especially an interactive ones. One way to cope with this problem is to break RTP/RTCP recommendations and use more than 5 % of session bandwidth. Another approach is to use method such as HA.

HA is one of the improvements for the RTCP protocol that has been recently introduced. Thanks to HA the idea of redundant data flow reduction has been advanced even further than any other RTCP improvement. It uses feedback targets and these feedback targets are organized hierarchically. With their help data redundancy can be removed at a short distance from the receiver and this gives us the ability to construct topologies ready for large-scale deployment where a huge number of receivers can be connected at the same time with low bandwidth consumption for RTCP protocol transmission. As described in detail in [3], HA can give even up to 100 times faster signaling gathering in comparison with the RFC 3550 RTCP standard, when in both cases 51 kbps bandwidth, and 10^5 receivers is present in the session [18]. The value 51 kbps equals the IPTV streaming with 1 Mbps reserved bandwidth for the service (i.e. 5 % of the whole service, as defined in RFC 3550).

In HA three types of members exist: sender, feedback targets and receivers. The sender transmits multimedia data, sender reports (SR-RTCP) and receiver summary packets (RSI-RTCP) to a multicast channel. The receivers receive multimedia data from the multicast channel and transmit receiver reports (RR-RTCP) to a feedback target via a unicast channel. These receiver reports contain information about the quality of reception and they can be also extended by an additional content (e.g. vote). And finally, feedback targets receive receiver reports (RR-RTCP) and they create statistics about QoS of these reporting receivers. RSI-RTCP messages are then created from many of these reports and they are transmitted to sender or another feedback target, when multilevel hierarchical aggregation is used (see Fig. 1).

In HA the receivers and feedback targets have to be organized in a hierarchical tree structure and the sender has to be informed about the size of each subgroup below feedback target, in other words, about how many members share the B_{RTCP} bandwidth. It is necessary to know this to be able to calculate the period lengths T_{RR}, and T_{RSI} as shown in equations (8), (9), (10) and (11):

$$T'_{\text{SR}} = \frac{L_{\text{SR}}}{25\ \% \cdot B_{\text{RTCP}}}, \quad (8)$$

$$T'_{\text{RSI\_S}} = \frac{L_{\text{RSI}}}{75\ \% \cdot B_{\text{RTCP}}}, \quad (9)$$

$$T'_{\text{RSI\_FT}} = \frac{L_{\text{RSI}} \cdot n_{\text{FT}}}{75\ \% \cdot B_{\text{RTCP}}}, \quad (10)$$

$$T'_{\text{RR}} = \frac{L_{\text{RR}} \cdot n_{\text{G\_R}}}{75\ \% \cdot B_{\text{RTCP}}}, \quad (11)$$

where $T'_{\text{RSI\_S}}$ stands for the time interval for sending RSI-RTCP message transmission from the sender, $T'_{\text{RSI\_FT}}$ stands for the time interval of the RSI-RTCP packet transmission from the feedback targets, n_{FT} and $n_{\text{G\_R}}$, give the number of neighbouring feedback targets or receivers that have a common feedback target in a single subgroup (see Fig. 1). All the formulas have to be compensated by the compensation factor C and its lower bound is limited to a constant of 5 seconds (4), (5) [17].

From these equations it is quite clear that especially for large scale sessions with huge number of receivers the traffic load over a network can be better spread and thanks to the aggregation also some degree of bandwidth reduction is possible.

III. Coordinate systems

The Internet coordinate systems are quite new approach how to localize hosts even in fixed networks. The major motivation for utilizing these methods is to optimize communication in the network and reduce bandwidth used in the same session size. And this is also our motivation of utilizing them in the field of HA. In the next few paragraphs the coordinate system types will be assessed from the perspective of HA.

The coordinate system methods can be divided into two basic groups: central based which utilizes landmarks and distributed one which are commonly based on physical model of spring network, which produces tension between hosts. [19]

A. *Centralized coordinate systems*

The Global Network Positioning (GNP) algorithm runs through two separate steps: first a set of landmarks is established and secondly the host position prediction is done. The landmarks are a subset of hosts which have a special role in the network and they create the backbone for the whole algorithm. Using them the hosts can predict their position while no high network traffic is generated.

The equation establishing the landmarks is a matter of seeking the minimum of the following function:

$$f\left(c_1^S; \dots; c_N^S\right) = \sum_{\mathcal{L}_i, \mathcal{L}_j \in \{\mathcal{L}_1 \dots, \mathcal{L}_N\} | i<j}^{N} \varepsilon\left(d_{\mathcal{L}_i\mathcal{L}_j}; d_{\mathcal{L}_i\mathcal{L}_j}^S\right), \quad (12)$$

$$N = n_{\mathcal{L}} * D, \quad (13)$$

the variable $n_{\mathcal{L}}$ stands for a number of landmarks, D is the space dimension, c_i^S is a coordination of a landmark L_i in synthetic space, d_{L_iLj} stands for the distance measured between the landmarks L_i and L_j, $d_{L_iL_j}^S$ stands for calculated distance between the landmarks L_i and L_j, ε stands for the square of error, and function f stands for the total sum of errors, for which we seek the minimum. See [1], [2], [6], [7] for a more detailed explanation of the algorithm. The measurement of distances is performed using the Internet Control Message Protocol (ICMP) protocol [16]. This protocol is used, for example, by the ping tool, which is available under many operating systems. The protocol measures the time delay between the initial packet transmission request and receiving the echo from the "pinged" host. This time is the so-called round-trip time (RTT).

Although the equation seems to be quite complex, it is based on a simple idea. The known variables are the distances measured and the unknown variables are the coordinates of landmarks, which will best fit the values measured. The number of unknown variables is expressed by formula (13). Each dimension of each landmark stands for a variable. The best host placement is found when the total function error is minimal. The equation thus takes the matrix of distances measured between all the landmarks, compares these values with the matrix of computed values and creates the sum of square of these deviations. Seeking optimal landmark coordinates is a matter of seeking for the minimum of function (12). Using this equation, we are even able to establish a set of landmarks from regular hosts, whose position is not know, but without any relevance to a real coordinate system (e.g. position on the map).

The second part of the algorithm localizes regular hosts. It is similar to the previous one, but now we aim to estimate the coordinates of a single host. The known variables are the RTT distances between the host and each of the set of landmarks that the host can measure. Then the estimation of the host coordinates is a matter of seeking the minimum of the following function:

$$f(c_H^S) = \sum_{\mathcal{L}_i \in \{\mathcal{L}_1 \dots, \mathcal{L}_N\}}^{N} \varepsilon(d_{\mathcal{L}_iH}; d_{\mathcal{L}_iH}^S) \quad (14)$$

In the case of equation (14), it is a D-dimensional function (see Equation (13)) and the total deviation between computed and measured values between the host H and landmarks $L_i \in \{L_1 \dots, L_N\}$ is computed.

B. *Distributed coordinate systems*

Other approaches can also use distributed coordinate systems. Their major representative is so-called Vivaldi method [19], which has also many variants and improvements that have been introduced recently, such as Myth [20], Pharos [21] and others. All can improve its accuracy and shorten the time of convergence to accurate values. These methods are commonly based on theoretical physical model of spring mesh, which are placed between hosts and the tension among these imaginary springs leads to minimize energy in the set of localized hosts. In terms of its accuracy the distributed coordinate systems are comparable with GNP, however its time of convergence to relatively accurate values is in case of Vivaldi significantly higher. Another issue is that it generates permanent traffic during the time of the session. When the network conditions are static, there is no need to measure the RTT distances again. On the other hand, the advantage of it is, that the structure of network is continuously adapted to the current network conditions, and therefore in dynamic network environments it would give better results. Furthermore, it seems that in decentralized coordinate it systems is quite difficult to utilize HA overhead for round-trip delay time measurement, which is necessary for every coordinate systems.

In some cases there might be beneficial to use a hybrid approach – distributed coordinate systems for feedback target (FT) stations and centralized GNP for receivers. Suitability of this approach strongly varies from case to case depending on the network type and network environment. If there are expected some network changes it is suggested to consider to use a distributed Vivaldi version where the session will adapt to actual network conditions. The drawback of this approach is its overhead traffic, which is for the immutable networks needless.

Currently we expect that most of the cases of HA deployment will be in static environments, and therefore the version described here is the centralized one. In this case it is also possible to periodically reset previously determined values and force to reinitialize the coordinates of all the hosts in the session. Thus it can, to some degree, also dynamically adapt to changing environments like the distributed ones.

IV. Integration of Host Position Prediction into Hierarchical Aggregation

In this section the integration of GNP method with HA is proposed. Because of hierarchical structure of HA, the coordinate system integration quite differs from the most common cases. In the first section we introduce a new session member type: so-called feedback target manager. The next sections describe tree initialization process which is needed for registration of FT hosts to the session.

A. Feedback Target Manager

As described in section II, in HA method feedback targets (FT) forms a tree, which is able to transmit signaling from huge number of receivers in a short time. This set of FT can be shared among several IPTV broadcasting and several parallel trees exists there. To organize these FT in the desired tree structure we introduce a new member type – so-called feedback target manager (FTM). This is a standalone application, which can be possibly run on the same hardware together with FT. However because of possibility of high network load, it is suggested to place FT on standalone station to reduce the risk of FTM service unavailability.

B. Tree Initialization

At the start of a session all the FTs need to be registered to FTM. Thus the FTM knows about them and when requested by an IPTV server it can create a new hierarchical tree. As mentioned earlier, there can be several trees sharing this set of FTs. Each tree is identified by a unique number and thus they can be distinguished between each other. During the time of a session, it is also possible that a new FT can join or, on the other hand, a FT can leave. FT leaving from a session can occur due to maintainers request or, of course, unexpectedly due to FT or network failure. For such events, we proposed a protocol, which monitors set of FTs and can detect breakdown of any of them in reasonable amount of time.

C. First Step – Landmark Backbone Establishment

As said in section III, the GNP algorithm proceeds in two steps. In the first step the landmarks positions are predicted and receivers are informed about the results. In the second step all the receivers predict their positions and select FTs where they will send their feedback. Each receiver selects its feedback according to the distance to FT and according to the number of receivers sending feedback to this FT (in other words, with how many other receivers or feedback targets the newly connected receiver will have to share the B_{RTCP} bandwidth). The ratio of these two parameters can be changed dynamically.

At the first glance it might seem that we would need an additional set of stations distributed over the Internet for host position prediction. Fortunately, for this purpose we can

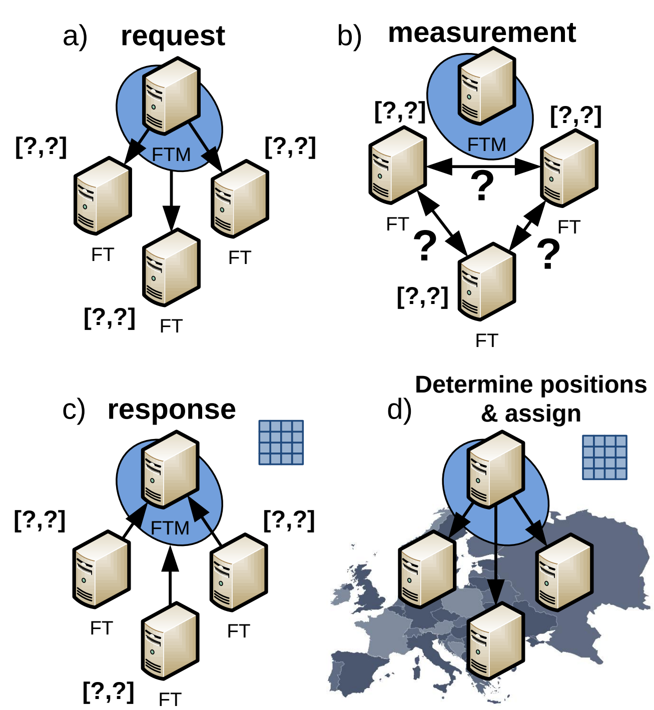

Fig. 2. Hierarchical aggregation scheme with many feedback targets.

utilize an existing set of FT stations as they are already

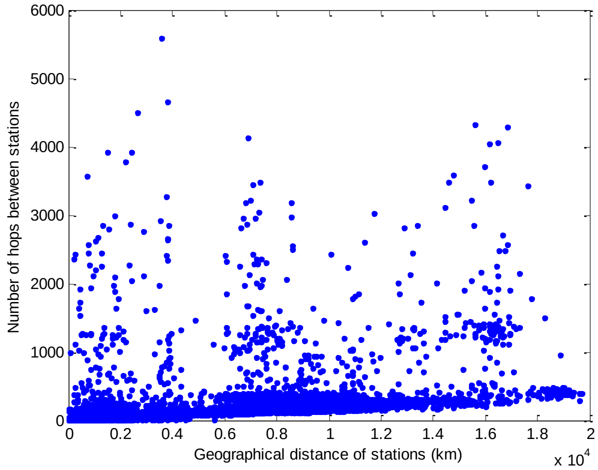

Fig. 3. Dependency of RTT measured between two hosts and their geographical distance. Results were obtained from the Planetlab experimental network. From the graph may not be noticeable, but 90 % of all measurements are in close linearly dependent area

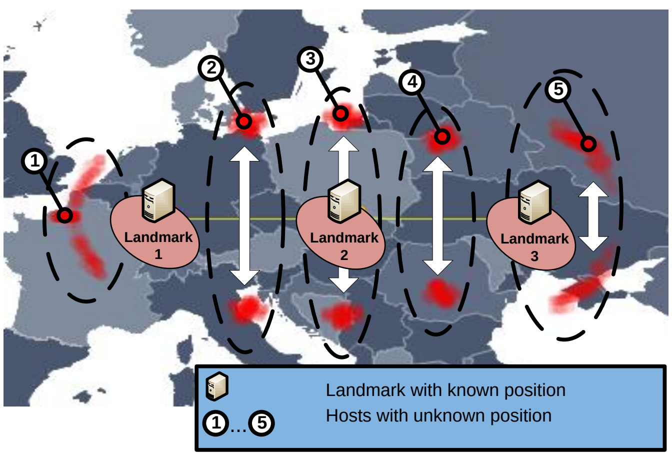

Fig. 4. Inaccurate position estimation when the triangular inequality condition is not fulfilled.

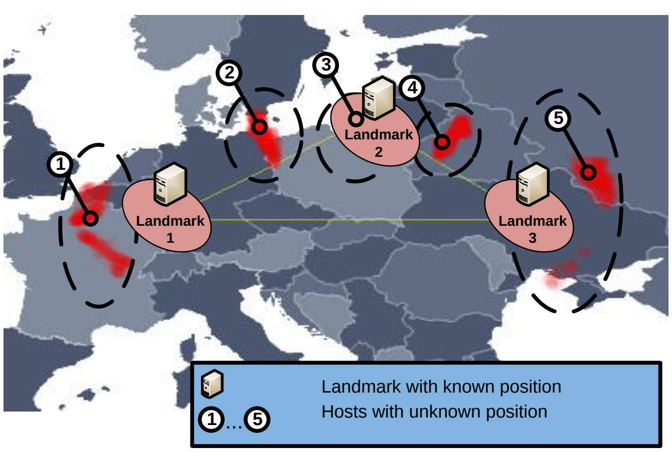

Fig. 5. Inaccurate position estimation when the triangular inequality condition is fulfilled.

distributed over the broadcasting area (or the whole Internet) and distance measurement generates relatively low overhead traffic in the network. This will have an effect that the traffic load will be distributed uniformly and the overlay network will be better organized, and consequently we can reduce risk of high traffic peaks in the network when some attractive poll is announced.

Let us look closer at the first step of the algorithm. It consists of 4 subparts: a) request from sender, b) measurement of RTT distances, c) establishment of distance matrix, d) and finally the localization of feedback targets (see Fig. 2). The sender request is transmitted in the RSI packet as a new block type of the RSI sub-report block [15]. When the feedback targets receive the request packet from sender, all the feedback targets will start measuring the RTT distances. To prevent network overflow, this measurement should be spread over the time length of $T_{\mathrm{RSI\_F}}$. Furthermore to reduce the risk of measurement during temporal network problems, the measurement should be repeated several times (e.g. three times). The resultant value should be the minimum of these values measured. Unfortunately, the risk cannot be completely eliminated. In such cases it fails it will affect the position estimation accuracy. As stated before, this measurement of RTT distances is performed using the ICMP [16] protocol. When all the feedback targets have measured the RTT distances to the other feedback targets, they will transmit these so-called vectors back to the sender. When the sender has a complete matrix of distances between the feedback targets, the sender will predict feedback target coordinates using equation (16) and transmit them via a multicast channel, to all the feedback targets and the receivers.

Informing the whole session about the landmark positions may seem to be a waste of bandwidth. However, the RTCP standard recons with possibility of there being one or more senders and therefore 25 % of the total RTCP bandwidth is reserved.

D. Second Step – Hosts Position Prediction

When the position of unknown landmarks has been predicted and all the landmarks form something like a basic network backbone of the whole algorithm, the position of regular hosts is to be predicted. Thanks to the fact that the number of landmarks is relatively low, the generated network traffic will not be very high.

When a receiver position has been predicted, the receiver should redirect its feedback to the best FT. The optimality of choosing a FT is here a matter of the distance to the receiver and the number of the other receivers reporting to the same FT.

In the section VI. it is also described a way how synthetic coordinate space can be mapped to a real map and how it can be utilized for statistics, e.g. for number of connected subscribers from different areas.

V. FEEDBACK TARGET PLACEMENT PROBLEM

At first glance it may seem quite surprising that the estimation of a host position can work, although it is based on measurement of RTT between two hosts and the structure of the Internet is quite complex. The Internet topology is based on a tree structure, rather than on the 2D space. However in spite of it, according to several measurements it has been approved [1], [2], [10], [11] that such approach can estimate relative distances between hosts in the network and thus save significantly amount of bandwidth, especially in large-scale environments. In Fig. 4 are depicted results obtained from measurements among approximately 350 stations in the Planetlab network, which spread worldwide. As you can see the dependency of distance on the RTT values are obvious and the most of the measurements forms a linear dependency.

A. Triangle inequality problem

In the coordinate systems is quite complex high-dimensional space mapped into some low-dimensional one. As these spaces are not homogenous, it might cause some degree of errors in some cases. Another factor that strongly affects resulting error of position estimation is the placements of landmark stations (or, in the case of HA, FT stations). The problem lies in the triangle inequality problem – when the landmark stations are in line, the algorithm gives exactly the same probability for prediction on the correct position as for a mirrored position (see Fig. 4). This is caused because the algorithm only considers the distance from host to landmark one, two and three and this value equals, also, the mirrored position. Naturally, the RTT measurement is also not absolutely accurate because of routers and switches latency and other unpredictable conditions and it is supposed that the total error is in average about 9 % ±3 % of the measured distance.

In the Fig. 4 are depicted five examples with error rate 9 % and normal distribution of this error with standard deviation 3 %. The probability of position estimation is depicted as the red area where its saturation stands for the probability of estimation on this position. As you can see on examples 2, 3, 4, 5, when the localized hosts are beside landmarks line, the probability of mirroring its real position is quite high. When the predicted host lies in landmarks line, the probability of host position estimation will not be mirrored, however also the accuracy is quite low (see hosts 1 in Fig. 4).

B. Effect of removing triangle

Now let us compare the previous results obtained with another, slightly modified, selection of landmarks. Rather than choose the landmark 2 in Slovakia (see Fig. 4), we placed it to Poland (see Fig. 5). Thus the triangular inequality condition was fulfilled and even the position of hosts 1, 2, 3, 4, 5 was kept the same as in the previous case. The results of host positions prediction is considerably better.

Of course, it is not always possible to choose from several FTs, especially in smaller networks. However if so, there is still high probability that the hosts will be formed in more effective manner than would be formed when chosen randomly. However, often there is a possibility to choose from several hosts and as such topology should serve for IPTV sessions for a long time. Therefore there could be motivation to address this issue. Because of presence of RTT measurement inaccuracy, it is not possible to rely on classical mathematical condition of triangular inequality. An example of this can be found in Fig. 5 – the landmark nodes 1, 2, 3 are not in line, however you can notice, that host no. 5 has some probability to be mirrored and the position can be predicted under the triangle consisting by vertexes landmark 1, landmark 2 and landmark 3.

C. Triangle inequality identification

To better evaluate if a selection of landmarks is good or not, the modified version of triangular inequality condition is introduced here in equation (15). Input parameters of this function a, b, c are RTT distances between any three hosts, where c must be greater or equal to a and b. T stands for a threshold. When T equals zero, all the combinations of hypotenuse and catheti will be considered as to be correct and the function I will return 0 (false) as the condition was not be violated. On the other hand, when threshold T equals one, only the equilateral triangle will be detected as to be correct.

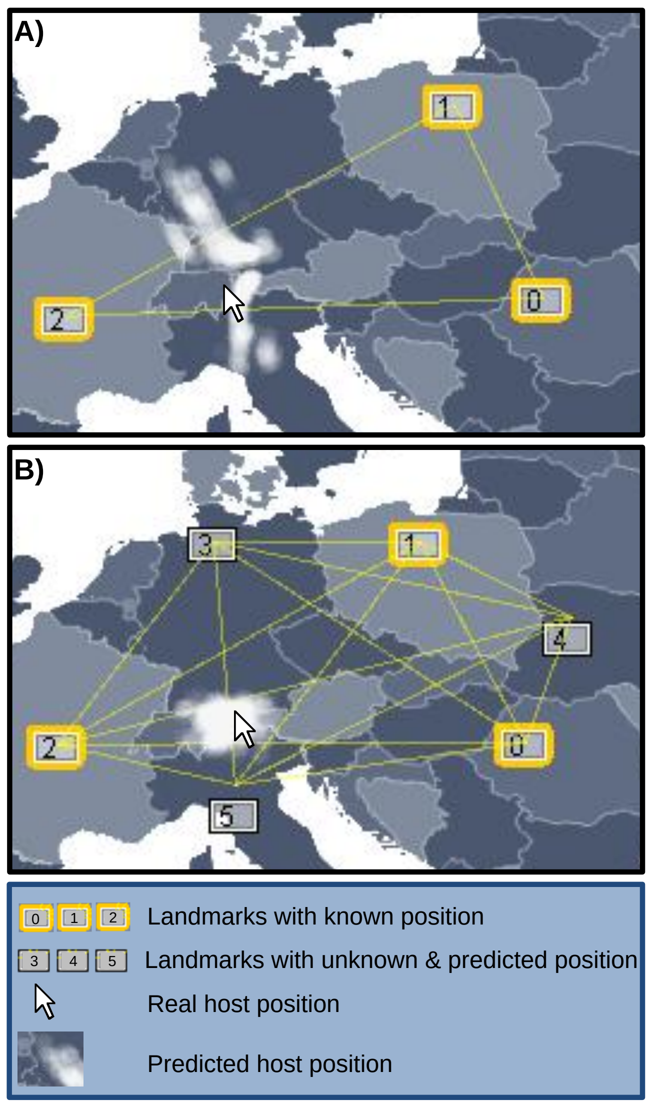

Fig. 7. Inaccurate host position prediction and its improvement with computationally predicted three new landmarks. Noise ratio was set to 20 %.

$$I(a,b,c) = \begin{cases} 0, & if\ \dfrac{a+b}{c} - 1 \geq \mathrm{T} \\ 1, & \text{otherwise} \end{cases} \tag{15}$$
$$\text{where } a \leq c \ \wedge b \leq c, T \in <0,1>$$

According to our empirical experiments it seems that value of 0.4 is sufficient, but it strongly depends on concrete landmarks placement. Of course, it strongly depends on a particular host positions and with more than 3 landmarks the results are also slightly different. To identify possible problems when deploying FT stations (landmarks) we developed a simulation with tool which is appropriate for a given type of coordinate system[1].

D. *Triangle Inequality Identification*

For the purpose of identifying the origins of the resulting prediction error when the GNP algorithm is used, a simulation tool has been developed, which has several options to be set (see Fig. 6). They are: the number of landmarks; noise ratio; and actual position of each landmark. The number of landmarks can grow from three, which is the minimal usable value for estimation in 2D space, up to one hundred. The landmarks positions can be set by mouse dragging and each landmark can be marked to indicate whether its position is known or unknown.

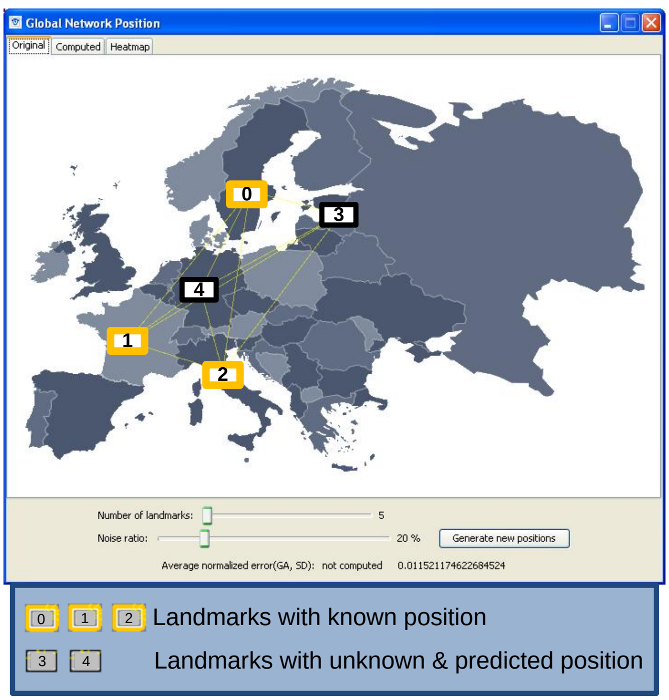

Fig. 6. GNP simulation tool with a config panel and landmarks position.

Known landmarks are shown with bold yellow borders (landmarks no. 0, 1, 2) (see Fig. 6) and unknown landmarks are shown with thin black borders (landmarks no. 3, 4, 5; see Fig. 6). The positions of these landmarks will be predicted in the first part of the algorithm (4). If the distances between landmarks and hosts were measured absolutely accurately, also the RTT distances would correspond accurately to the map distances. However this does not correspond to reality. In real network conditions, the round-trip time and the real-map distance cannot be mapped absolutely accurately because of the difference between Euclidean space and network structures. To take this inaccuracy into account the option "noise ratio" assists. It can scale from the value of 0 %, which stands for absolutely accurate measuring, to 100 %. The value 100 % says that such a virtually measured RTT value is obscured by noise ranging from ±100 % which means range from 0 % to 200 % of its original distance.

Let us assume a case when we know the position of only a limited number of landmarks (e.g. three) and they are placed as depicted in Fig. 7A – one in Romania, one in Poland and one in France and all the RTT measurement is obscured by 20 % noise. In this case the position prediction for the host placed in Germany is quite inaccurate (see Fig. 7A). The probability of position prediction is spread over a huge area beginning in the centre of Germany through Switzerland, Austria up to Italy.

As the simulation results have shown, the algorithm, for such a configuration, does not give very good outcomes. Especially when the host is near the French landmark, the prediction can be affected by quite big error with a big diversion from the real position. It is obvious that a new landmark should be added, which should be placed somewhere near Germany. If we had enough landmarks and their positions, it would be quite easy. We would just select a suitable passive landmark from this area and then activate it. However, when the network structure is dynamically changing and new landmarks must emerge dynamically, it might be problem.

VI. Mapping from Imaginary Space onto Real Position Space

Except reduction of bandwidth used, the integration of HA with coordinate systems can also offer estimation of subscriber positions. For this purpose there is better idea to use instead of a synthetic coordinate space use a one mapped to a real world coordinates, e.g. geographical map or the GPS space.

What should be also emphasized is that internet coordinate systems were not proposed for accurate position prediction on a geographical map and, therefore, they do not give such accurate results as other methods can give. Their main objective is to allow building more effective overlay structure. As they are already deployed, they can give approximate estimation of receiver positions with only a little overhead.

In a real network, a set of all landmarks $\mathcal{L}_{\mathrm{A}} = \{\mathcal{L}_1, \mathcal{L}_2, \ldots, \mathcal{L}_N\}$ can be divided into two separate subsets: set of landmarks, whose positions are unknown (denoted $\mathcal{L}_{\mathrm{U}}$) and a set of landmarks whose positions are well known (denoted $\mathcal{L}_{\mathrm{K}}$). Obviously, for hosts with known position we do not need to estimate their coordinates. When we take this fact into account, equations (12), (13), and (14) can be changed to the following forms:

[1] http://adela.utko.feec.vutbr.cz/projects/global-netwok-positioning.html

$$f_{\mathrm{obj}}\left(c^{\mathrm{S}}_{\mathcal{L}_{\mathrm{U1}}}, \dots, c^{\mathrm{S}}_{\mathcal{L}_{\mathrm{UN}}}\right) = \varepsilon_{\mathrm{CD}} + \varepsilon_{\mathrm{DD}}, \quad \mathcal{L}_{\mathrm{U1}}, \mathcal{L}_{\mathrm{U2}}, \dots, \mathcal{L}_{\mathrm{UN}} \in \mathcal{L}_{\mathrm{U}} \tag{16}$$

$$\varepsilon_{\mathrm{CD}} = \sum_{\mathcal{L}_i \in \mathcal{L}_K, \mathcal{L}_j \in \mathcal{L}_U} \varepsilon\left(S \cdot d_{\mathcal{L}_i,\mathcal{L}_j}, d^{\mathrm{S}}_{\mathcal{L}_i,\mathcal{L}_j}\right), \tag{17}$$

$$\varepsilon_{\mathrm{DD}} = \sum_{\mathcal{L}_i,\mathcal{L}_j \in \mathcal{L}_U | i<j} \varepsilon\left(S \cdot d_{\mathcal{L}_i,\mathcal{L}_j}, d^{\mathrm{S}}_{\mathcal{L}_i,\mathcal{L}_j}\right), \tag{18}$$

$$f_{\mathrm{obj}}\left(c^{\mathrm{S}}_{\mathrm{H}}\right) = \sum_{\mathcal{L}_i \in \{\mathcal{L}_1, \mathcal{L}_2, \dots, \mathcal{L}_N\}} \varepsilon\left(d_{\mathrm{H},\mathcal{L}_i} \cdot S, d^{\mathrm{S}}_{\mathrm{H},\mathcal{L}_i}\right), \tag{19}$$

$$S = \frac{\sum_{\mathcal{L}_i,\mathcal{L}_j \in \mathcal{L}_{\mathrm{K}}} \left(\frac{d^{\mathrm{S}}_{\mathcal{L}_i,\mathcal{L}_j}}{d_{\mathcal{L}_i,\mathcal{L}_j}} \right)}{\binom{N}{2}} = \frac{2 \cdot \sum_{\mathcal{L}_i,\mathcal{L}_j \in \mathcal{L}_{\mathrm{K}}} \left(\frac{d^{\mathrm{S}}_{\mathcal{L}_i,\mathcal{L}_j}}{d_{\mathcal{L}_i,\mathcal{L}_j}} \right)}{N^2 - N}, \tag{20}$$

where $\varepsilon_{\mathrm{CD}}$ stands for the total sum of squares of deviations of computed distances from measured distances. These distances are computed among the relation $\mathcal{L}_{\mathrm{K}} \times \mathcal{L}_{\mathrm{U}}$, i.e. between hosts from set of known landmarks $\mathcal{L}_{\mathrm{K}}$ and from a set of unknown landmarks. $\varepsilon_{\mathrm{DD}}$ stands for the total sum of square deviations between computed and measured distances. Here the distances are computed among the relation $\mathcal{L}_{\mathrm{U}} \times \mathcal{L}_{\mathrm{U}}$, i.e. between all the hosts from a set of unknown landmarks.

To make it clearer, see Fig. 8, where hosts with known positions are marked (K) and hosts with unknown and predicted positions are marked (U). What should be emphasized is the fact that distance between the known landmarks (K) is used only for the computation of scale factor S (20), and not for the estimation of landmarks position, where it is obtained by calculating an average ratio between RTT distances and distances in the coordination space.

What is newly introduced here is the scale factor S and the function $f_{\mathrm{obj}}\left(c^{\mathrm{S}}_{\mathcal{L}_{\mathrm{U1}}}, \dots, c^{\mathrm{S}}_{\mathcal{L}_{\mathrm{UN}}}\right)$, which computes the total deviation of computed-space and RTT-space distances among set of known landmarks and a set of unknown landmarks. The scale factor is a mean of the RTT among all the landmarks of the set of known landmarks $\mathcal{L}_{\mathrm{K}}$. The equation compares the measured distances d^{S} with the real distance d, e.g. on a map. By the use of it, the measured values can be scaled to be comparable with the real positions on a map. In the case of GNP positioning, the algorithm is based on imaginary values that have no reference to any real distance or position. As the RTT distances and the real distances may not be homogenous spaces, the S may involve an error. At any rate, the value of round-trip time correlates with the distance values and therefore can be used as estimate for the network position.

Equation (16) has a similar function as original equation (12) except that it does not change the position of known landmarks $\mathcal{L}_{\mathrm{K}}$. It only predicts the position of the unknown landmarks, which belong to the set $\mathcal{L}_{\mathrm{U}}$. Furthermore, thanks to the scale factor, there are not RTT units of milliseconds but some other units (kilometers / meters) that fit better to the distance quantity.

With these equations the section IV. D can be extended with following few things: all the hosts receive from the multicast channel information about the network scale factor S (20), about all the landmarks and their coordinates and, in addition, they can measure the RTT distances to the landmarks (or FTs in case of HA). This is all that is needed to predict their own positions (see formula (19)). As mentioned before in this text, the RTT measurement should be performed several times to minimize the chance of affecting the RTT measurement by some network problems. When the receiver knows the RTT distances to all the landmarks, it can start predicting its own position using formula (19). In fact, it is a matter of seeking such coordinates for which the equation gives a minimum error. For this purpose, some multidimensional optimization algorithm should be used such as the simplex downhill, a gradient method or a kind of genetics algorithm, which can give most accurate results especially for bigger numbers of FTs.

As the hosts positions are scaled using the scale factor S, the values can have relevance to some real positions.

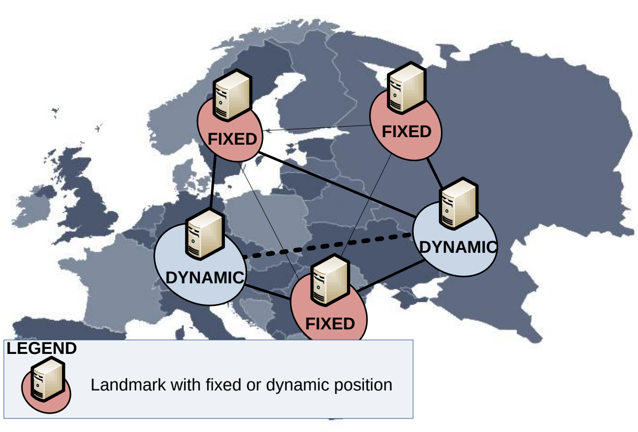

Fig. 8. Set of landmarks with known position (K) and set of landmarks with unknown position (U).

VII. Benefits of Integration of Hierarchical Aggregation with Internet Coordinate Systems

The effect of integrating internet coordinate systems with HA as shown in Fig. 9. In this figure all the stations are in both cases A) and B) on the same position. The difference is that in the case A) receivers select the target for their feedback reports randomly. In the case of B) all the receivers select the nearest one using internet coordinate system. It is obvious, that the communication in the case B) is significantly more effective and in this particular case the bandwidth on some routing points has been saved by up to 37 %.

Of course it is also possible to localize receivers simply by measuring RTT distance and selecting the one, which is the nearest one. A narrow neck of such a solution is that when the set of FTs is shared among several IPTV broadcasting, all the time when the program is switched, it might use a different stations and the measurement have to be repeated. Second and even more important issue arise when the receiver is mobile and its position changes in time. In this case the measurement should be periodically repeated and this would generate significant additional overhead traffic not even at the beginning of the session but continuously during the entire time of the session.

VIII. Scalability Scenarios

When the classic Hypertext Transfer Protocol (HTTP) is used, the speed of signaling transmission is limited only by the capacity of a network. This approach has a disadvantage in that it may lead to traffic peaks and might affect other services, in particular when an attractive program is broadcasted. The RTCP protocol is designed to deal with such an issue. It uses a constant bandwidth and when the number of users grows, the time period for receiver signaling grows too. Thus the traffic is spread in time and traffic peaks can be avoided. However, the disadvantage of such an approach is that for a big number of receivers the resulting period might become rather long. A simple solution can be assigning more bandwidth. It is expected that the feedback channel will be used not only for a simple monitoring of QoS, as used today in the RTCP protocol, but also for new value-added services such as interactive TV. Therefore it is supposed that it will not be a big barrier for IPTV service providers to assign more bandwidth than currently defined in standard RTCP. However, especially in bigger countries and in the case of multination programs (sporting events), the number of viewers can achieve even tens of millions of viewers at a time. Particularly in such scenarios, the compromise between bandwidth and signaling propagation period is not sufficient and can lead to high bandwidth consumption and long propagation time periods.

The HA brings a new architecture where compromising between time and bandwidth is extended to a number of FTs. The advantage of HA is that it can, in addition, significantly reduce the traffic in the network a) by spreading the load between several FTs and b) by aggregating receiver signalizations at the nearest FT. Here the aggregation can significantly reduce the length of the message (it is a kind of histogram and thus the length of the packet can remain constant for almost any number of receivers in the session). In Fig. 10, several scenarios of the dependence of resulting signaling propagation time on the number of receivers and bandwidth assigned is depicted. All of them suppose that the HA tree is ideally balanced and the number of receivers is, except Figure 10 b), in the range of 1 to 25 million and the feedback channel bandwidth scales from 128 kbps to 3.2 Mbps. The cases a) and b) depict exactly the same scenarios, the only difference is that b) is focused on the area where the resulting propagation time is below 15 seconds and thus limited to the number of receivers from 1 to 250 000. The cases with 1 FT, 10 FTs, 30 FTs, 50 FTs, 100 FTs, 200 FTs and 500 FTs are depicted, where the case with 1 FT stands for RTCP standard. The area where the resulting signaling propagation time is below 15 seconds is marked in blue color.

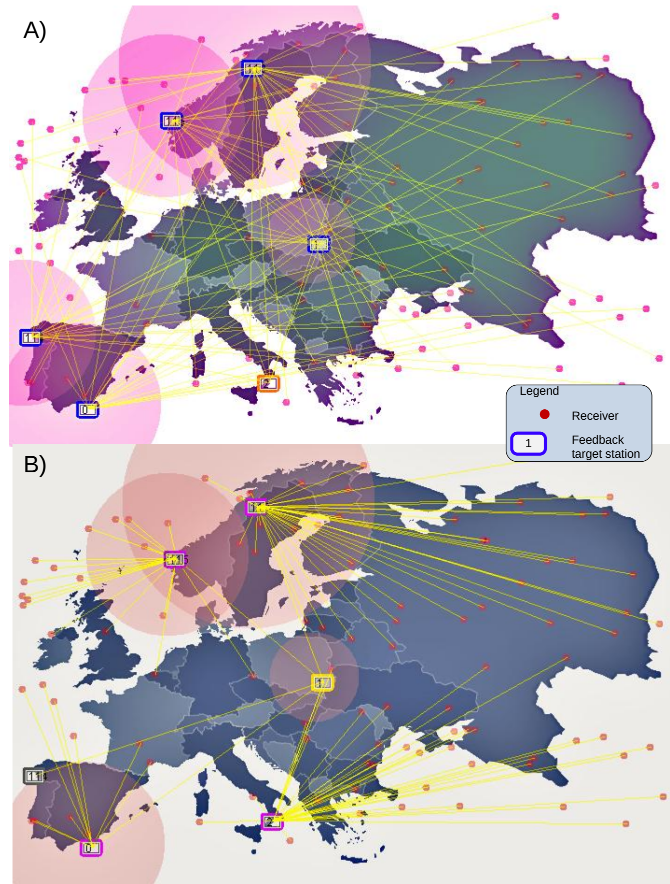

Fig. 9. Example of A) randomly selected FT stations and stations and B) selection using internet coordinate systems. The positions of receivers and FT stations are the same in both cases.

IX. Deployment of HA in a Real IPTV Infrastructure

The original motivation of this work was targeted to design a scalable structure for needs of interactive IPTV service. The idea behind it is to provide to an IPTV service provider a technology, which will be capable to efficiently transmit receiver signaling and can enable fast interaction between viewers and a content provider. Common IPTV service consists of RTP and RTCP protocols. HA builds on the basis of RTCP protocol and only a few changes are needed. Namely adding the internet coordinates system support to receivers and, of course, adding support for a new type of packets and new type of blocks in RTCP messages.

Second scenario is to target the feedback channel to a content provider rather than to each IPTV service provider. Subscribers of several IPTV service providers complemented by regular TV subscribers equipped with access to the Internet can make up a number of viewers and their votes are related only to distributed content.

The proposed idea is also quite general and might be used not only in the field of IPTV service, but also in any case where there is a need for transmitting the signaling from a number of receivers to a single point.

X. Conclusion

Nowadays we can be witnesses of the growing influence of IPTV on almost all parts of the developed world. According to several independent marketing analyses it seems that this trend will remain at least for further several years. This, of course, will mean more IPTV subscribers. Furthermore, if we take an expansion of mobile multimedia devices into account the growth of number of IPTV subscribers can even accelerate.

HA will provide facilities for future growth in the number of subscribers and will be scalable enough not only for time to time sending response on some poll or question, but can provide a continuous and scalable feedback transmission for all the receivers in the session, which can convey their opinion during the entire duration of a television program. This will also provide a new kind of knowledge as it will be cheap, really fast and easy to get an opinion from all the subscribers.

There are already several solutions how to enable interaction between subscribers and a content provider. In this paper was introduced an improvement of HA method and described the proposed prototype of hierarchical aggregation with internet coordinate systems.

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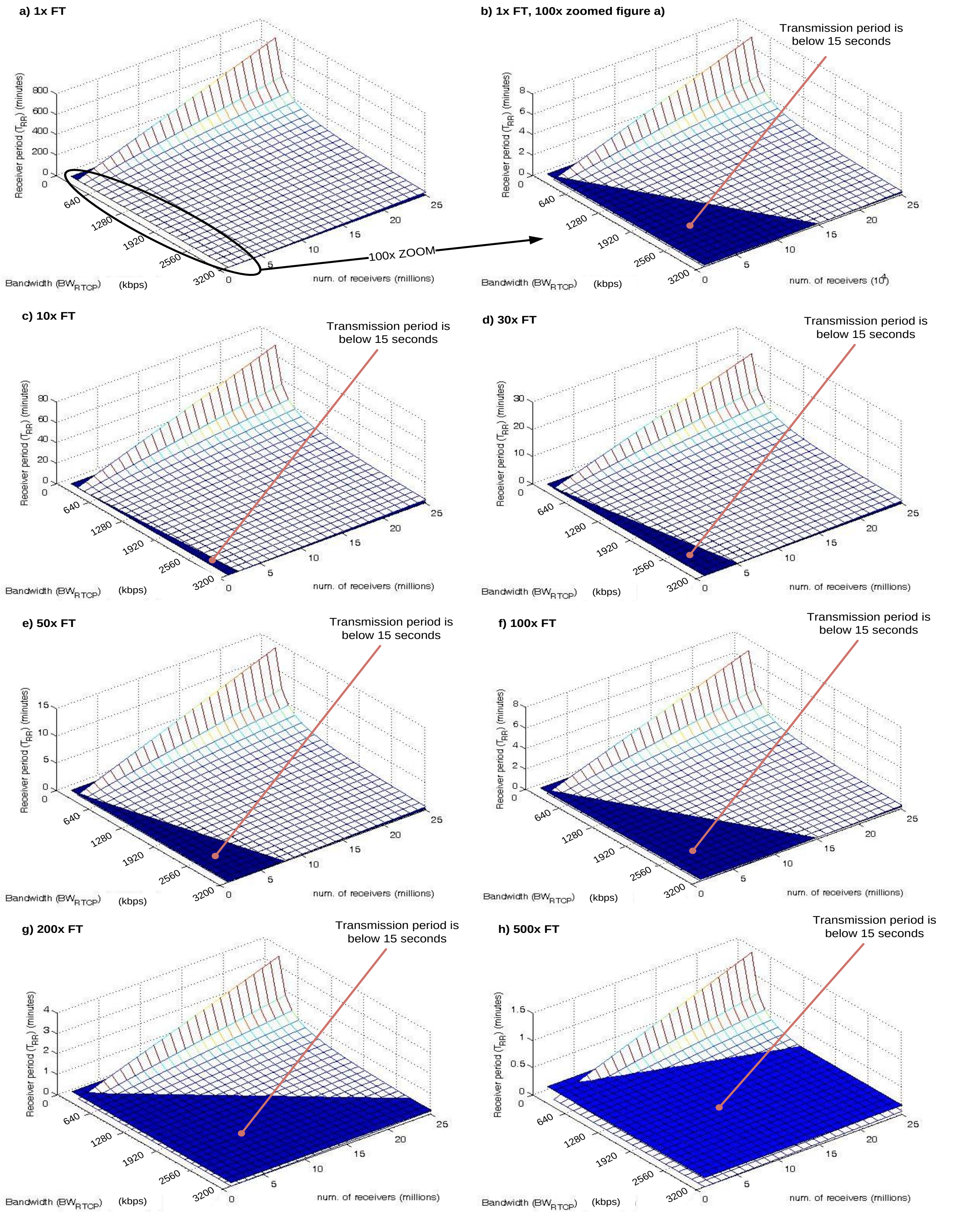

Fig. 10. Dependency of signaling propagation time on number of receivers and bandwidth assigned to feedback channel. The blue color marks the areas, where the resulting propagation time is below 15 seconds (10 seconds on the level of receivers and 5 seconds on the level of FTs). The bandwidth is in from 128 kbps to 3.2 Mbps. The number of users are in millions, except of b) where there is depicted the 100x zoomed a) figure.