Effectiveness of Overlay Multicasting in Mobile Ad-Hoc Network

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***Abstract*—This paper investigates the effectiveness of the application level multicasting, named overlay multicasting, with respect to the network layer one in Mobile Ad Hoc Networks (MANET). With respect to network layer multicasting, in overlay multicasting only the mobile nodes participating to the multicast group exploit the multicast routing at application level, while the other nodes of the MANET simply perform unicast IP routing. This constraint in the possibility of use multicast routing in all nodes leads to a loss of efficiency in the bandwidth usage that we aims to discuss in this paper. The parameter used for the comparison is the cost of the multicast distribution tree, which is built by means of Steiner based algorithms. We measure this parameter by means of an exhaustive simulation campaign, analysing the performance dependence versus different parameters: device coverage range, number of MANET nodes, multicast group size and mobility model.**

Keywords: overlay network, ad-hoc network, multicast, Steiner tree.

I. INTRODUCTION

A Mobile Ad Hoc Network (MANET) consists of a set of mobile nodes that communicate each other on wireless media, without the need of fixed network infrastructure. Since the radio transmitters have a limited range (e.g. if Wi-Fi is considered a typical value is 100 m), distant nodes can communicate by the auxilium of other nodes through a multi-hop path. Thus, each terminal belonging to the network acts not only as end-system but also as router, forwarding data packets. This behaviour can assure connectivity in environments with high density of mobile nodes with respect the transmission range. Typical MANET scenarios are: 1) disaster recovery situations where fixed network infrastructure is damaged and many rescue people are deployed; 2) battlefield where an entire platoon is advancing. In both scenarios the individuals are equipped with a communicating device participating to the MANET. In addition, we can imagine that the individuals are together grouped and each group is led by a leader, which dispose of a powerful communicating device. Within this vision, multicast applications [2] (e.g., video-audio conferencing) may be important because they could allow a high level of cooperation between the operation's leaders.

Usually, multicast applications are supported by specific routing protocols designed to optimise some parameters and the conventional wisdom leads this routing enhancement to lie within the IP network layer. In this case, the application fully relays on the network layer to deliver the data flow to all the seek terminals, which are seen as a unique entity. Obviously, this approach requires that the nodes of the MANET support and agree on a specific multicast protocol. Nevertheless, this occurrence is hard to reach in environments with heterogeneous devices like the MANET one. As a matter of fact, some devices may own enough computational capacity to easily run the network layer multicast protocol, whereas other simple terminals may not. Moreover, even in fixed network, issues like scalability, deployment, reliability, etc. still maintain some doubts on which is the best-multicast protocol to be implemented in IP routers [1] and these uncertainness reflect themselves also in MANET environment with the addition of mobility issues [2].

To overcome this stalemate, the idea of employ the multicast protocol at application level seems promising both in fixed [4][5] and in MANET environments [6][7]. The nodes of the multicast group form together an overlay network, which links are UDP or TCP connections supported by the underlying IP unicast protocol. On top of this overlay connectivity, the nodes of the multicast group perform the agreed multicast routing.

The overlay approach gets both pro and cons. The pro consists in its deployment simplicity (the protocol has to be agreed only among the participants) and in its implementation simplicity (due to the restricted number of cooperating protocol entities). The cons consists in a partial removal of routing intelligence by the nodes of the network that may yield some penalties in terms of bandwidth usage.

In this paper we investigate the inefficiency of the overlay multicasting solution in mobile ad-hoc networks with respect to the network layer multicasting by comparing the distribution tree cost of the different solutions. Our work is consistent with the topic faced in [6][7], in which some results are presented to prove the effectiveness of novel overlay multicast protocols. The current work does not propose any novel protocol but research on the "intrinsic" inefficiency of the overlay multicasting in specific MANET environments. We use optimal tree algorithms and don't care of any networking or computational impairments, a part from the coverage range of the transmitting device. So doing, the outcoming inefficiency is only due to: i) the shift of the multicast routing from the network to application layer; ii) the specific MANET environment.

The paper is organized as follow: section 2 points out the overlay inefficiency problem; section 3 discuss on the adopted measuring approach; section 4 describe the simulation scenario on which the measuring approach is based on; section 5 report the numerical results and discuss on the overlay efficiency dependences on the system parameters; finally, in section 6 conclusions are drown.

II. OVERLAY MULTICASTING INEFFICIENCY OVERVIEW

Many merit parameters can be used to evaluate the performances of multicast protocols, depending on the considered network and application [3]. Since we are considering wireless mobile ad-hoc networks without facing with computational and network impairments, the only relevant performance parameter results in the cost of the multicast distribution tree, which is directly related to the bandwidth consumption of the multicast communication.

Let us assume that all the "network links" get a given cost. We define the cost of the multicast distribution tree as the sum of the cost of each "link of the tree". The cost of a link of the tree is equal to the sum of the costs of the network links on which it is based on.

For network layer multicasting each link of the tree corresponds with a different network link; this means that each network link delivers only one copy of a multicast data packet, so minimizing the overall required bandwidth, i.e. the tree cost.

In the overlay case, a link of the multicast distribution tree (i.e., an overlay link) may be realised by means of several network links; moreover, a network link may be stressed by several overlay links, due to the lack of multicast routing within the legacy nodes. These stressed network links have to deliver a number of copies of the same packet equal to the number of overlay links that they are supporting. This occurrence wastes the bandwidth respect to the network layer multicasting, i.e. it produces higher tree cost.

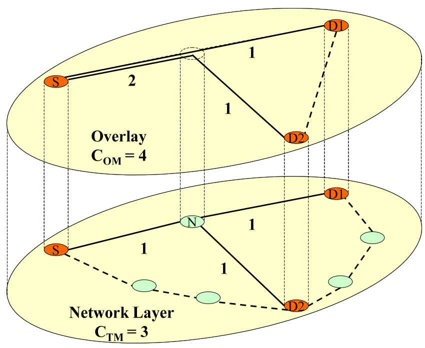

Figure 1. Example of overlay multicasting.

As example, let us consider the situation reported in Fig 1. Eight terminals compose the network, while three terminals (S, D1 and D2) participate to the multicast group, where S is the source. When the network layer multicasting is used (lower oval) all the terminals provide the multicast functionality. So, assuming an unitary cost for each network link, the solid lines represent the resulting multicast tree. Otherwise, when the overlay multicasting is used, only the terminals participating the multicast group provide multicast functionalities. In this case (upper oval) the solid lines represent the overlay multicast distribution tree and the relevant link cost is reported. It can be noted that link S-N is stressed twice. In terms of used bandwidth, the network layer multicasting requires three packet transmissions (i.e., the tree cost C_{TM} is equal to 3), while four packet transmissions are required in case of overlay multicasting (i.e., the overlay tree cost C_{OM} is equal to 4).

III. MEASURING APPROACH

In this section, we discuss on the measuring approach utilised to evaluate the outcoming overlay inefficiency. We represent the mobile ad-hoc network as a dynamic graph denoted as G=(V,E), where the vertices V are the mobile nodes and the edges E are the wireless network links. For each network link we assume a unitary cost. Moreover, we represent the overlay network with the graph $G_M=(V_M,E_M)$ for which the vertices V_M are nodes of the multicast group and the edges E_M are the connecting overlay links. As previously mentioned, the overlay links are transport level connections and so have to be considered as logic links with a cost equal to the sum of the costs of the supporting network links.

While the set E of network links is well defined by the radio coverage, the set E_M is an open choice. Tacking into account the goal of finding performance bounds, we have to consider an overlay connectivity topology E_M able to allow the multicast construction tree algorithm to find the optimal solution. Assuming to own the optimal algorithm, the optimal solution will be found only if this algorithm is able to search on all the possible overlay paths. For this reason E_M must result in the full meshed topology.

At this point we have, on the one hand, the network level graph G and, on the other hand, the full meshed overlay graph G_M. To evaluate the overlay inefficiency, we use optimal construction tree algorithms on G and G_M and compare the relevant tree costs.

Let us discuss now on the employed construction tree algorithms. In the overlay case, because all the vertices V_M have to be connected, the problem of finding the optimal tree resorts in a minimum spanning tree one. Therefore, to obtain the overlay optimal tree we recur to the PRIM algorithm [8] applied on G_M. Instead, the evaluation of the minimum spanning tree for the G graph is a typical Steiner tree problem that has been proved to be NP-complete, and no algorithms can solve it in polynomial time. Hence, for the layer three multicasting we evaluate the optimal tree recurring to the TM heuristic algorithm [9] applied on G [(1)].

IV. SIMULATION SCENARIO

The previously discussed measuring approach is applied to simulated network topologies. We refers to a two dimensional

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[1] We have also utilised the KMB algorithm, but TM outperforms

area A in which the node movements are regulated by a specific mobility model.

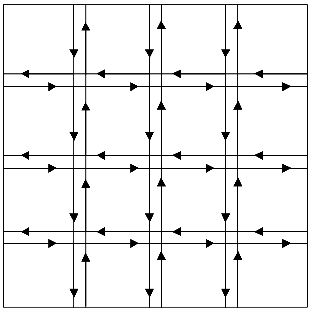

Figure 2 Map of the Manhattan mobility model

The dynamic of the MANET is roughly taken into account by means of a sequence of snapshots. In the snapshot i-th we perform the following procedure:

1) randomly place N nodes in the allowed space and chose M nodes as forming the multicast group;
2) compute the network connectivity graph G(i) taken into account that the coverage range of the radio devices is R meters and that, if the radio connectivity between two nodes exists, then a network link between these nodes exists too;
3) compute the full meshed overlay connectivity $G_M(i)$ and the relevant overlay link costs. If it is not possible to connects all the nodes of the multicast group for absence of network links, the snapshot is declared as "not-connecting" and the procedure is terminated, otherwise the snapshot is declared as "connecting" and the procedure is continued as follow;
4) find the multicast distribution tree and evaluate the tree costs $C_{TM}(i)$, in case of layer tree multicasting, and $C_{OV}(i)$, in case of overlay multicasting.

After an abundant number of snapshots, we evaluate the average value of $C_{TM}(i)$, $C_{OV}(i)$ (named C_{TM} and C_{OV} respectively) excluding the "not-connecting" snapshots. For our purpose of comparison, we define *efficiency* of the overlay multicasting the ratio C_{TM} / C_{OV} .

V. NUMERICAL RESULTS

In this section we discuss on the efficiency of the overlay multicasting varying the coverage range R, the mobility model, the multicast group size GS and the number of MANET nodes N. In all cases we refer to a square mobility area A of size 1000m x 1000m.

The considered variability ranges of these parameters allow us to analyse the overlay efficiency levers in practical cases of interest.

As far as the coverage range is concerned, we consider two values: 100 and 250 meters. The former is consistent with the IEEE 802.11 technology and the latter with other literature investigations on the same topic [6][7].

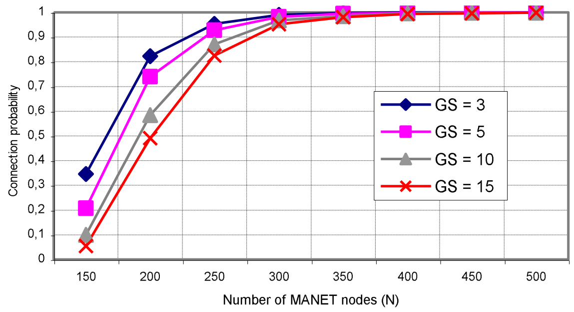

Figure 3– Connection probability of the multicast group for coverage range R =100 m and FS mobility model, varying the number of nodes N and the multicast group size GS

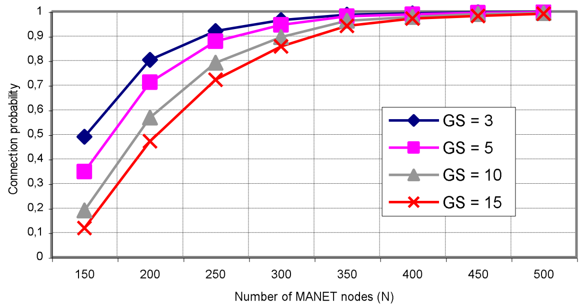

Figure 4– Connection probability of the multicast group for coverage range R =100 m and MN mobility model, varying the number of nodes N and the multicast group size GS

We consider two kinds of mobility models: free space (FS) and Manhattan (MN) [10]. In the free space mobility model the nodes are able to move in the entire area; whereas, in the Manhattan model the node may move them only on lines (i.e., the streets) defined on the map (Fig 2). These models are representative of situations of person deployment in an open space (the FS model) and in a city (the Manhattan model).

Finally, the size GS of the multicast group has been varied from 3 to 15.

The number of nodes forming the MANET, denoted with N, is an important parameter because a sufficient number of nodes is necessary to offer a "reasonable" connection probability among the multicast group. A preliminary analysis must be performed to validate the selected range. Fig 3 and Fig 4 show the connection probability in case of R = 100 meters for the FS and MN mobility model respectively, that is evaluated as the ratio among number of "connecting" snapshots and the overall number of snapshots. In both cases of mobility, to obtain a reasonable connection probability, the required number of nodes N is grater than 250. For smaller values of N the connection probability is so small to yield the scenario as impractical for the high service unreliability. Fig 5 and Fig 6 report the same probability in case of R = 250 meters; as expected, with the increase in the coverage range, the number of nodes required to obtain a reasonable connection probability decreases as well and satisfactory values lies above 40.

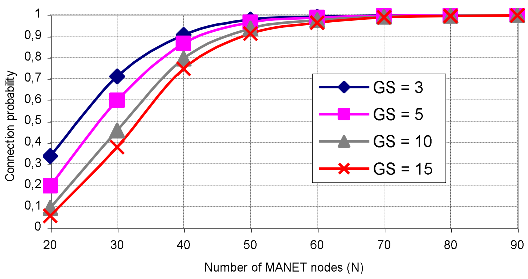

Figure 5– Connection probability of the multicast group for coverage range R =250 m and FS mobility model, varying the number of nodes N and the multicast group size GS

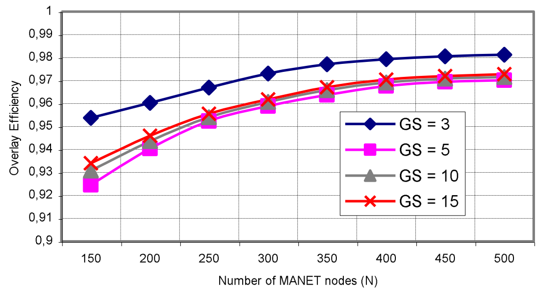

Figure 7– Efficiency of the overlay multicasting of for coverage range R =100 m and FS mobility model, varying the number of nodes N and the multicast group size GS

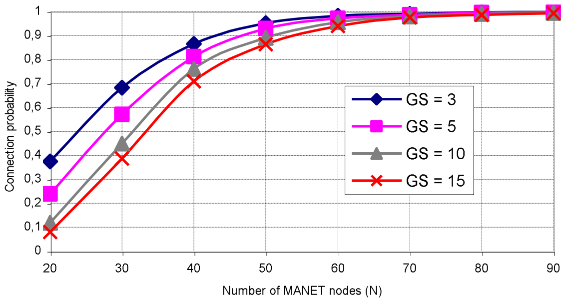

Figure 6– Connection probability of the multicast group for coverage range R =250 m and MN mobility model, varying the number of nodes N and the multicast group size GS

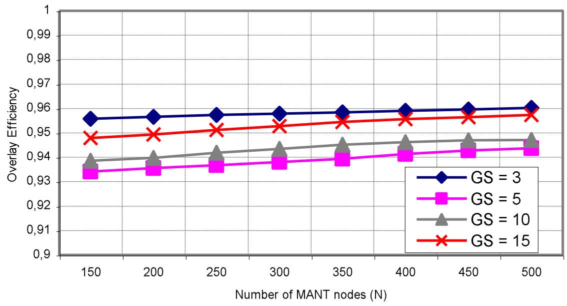

Figure 8– Efficiency of the overlay multicasting of for coverage range R =100 m and MN mobility model, varying the number of nodes N and the multicast group size GS

Fig 7, Fig 8, Fig 9 and Fig 10 show the measured overlay efficiency versus the number of nodes in case of R equal to 100 meters and 250 meters for different values of group size and mobility model. Based on these graphs, the main deduction is that: in MANET, once we assure an acceptable multicast connection probability by a sufficient number of nodes, the efficiency of the overlay multicasting, measured as the ratio of the network level and the overlay tree costs, is above the ninety percentage. To get in more detail, in the following we discuss on the dependences of the overlay multicast efficiency on N, R and GS.

A. Dependence on the number of MANET nodes (N)

All the results presented in Figs 7÷10 show that with the increase in the number of MANET nodes(N), the efficiency increases towards a certain saturation value. This behaviour may be explained as follow: the overlay inefficiency is due the limited number of nodes on which we can operate to optimise the multicast tree. This leads, in the overlay case, to the presence of "bottleneck" network nodes, which are stressed by several overlay connections. The increase in the number of network nodes yields more probably that the overlay connections insist on different network paths, so reducing the presence of bottleneck nodes and hence increasing the efficiency.

However, the presence of bottleneck network nodes is also due to the mobility model.

In fact, the Manhattan model with respect to the Free Space one, may implies a greater number of bottleneck nodes, because the nodes at the building edge may act as topological bottlenecks. This leads the overlay efficiency in the MN case (Fig 8, Fig 10) to be lower than the same one in the FS case (Fig 7, Fig 9). Anyway, the overlay efficiency reaches a saturation value, due to the intrinsic overlay limitations in optimising on the overall number of network nodes.

B. Dependence on the device coverage range (R)

With the increase in the coverage range, the number of network nodes involved in the overlay connectivity decreases. As consequence, the set of network nodes on which the TM algorithm operates tends to the multicast group and the lack of overlay efficiency tends to reduce as well. This occurrence is highlighted by the comparison of Fig 7 (Fig 8) with Fig 9 (Fig 10), where the efficiency obtained in the R = 250 m case outperforms the one in the R = 100 m case.

C. Dependence on the multicast group size (GS)

In order to explain the behaviour of the overlay efficiency versus the size of the multicast group (GS), let us first consider the case of GS=2. In this case none network nodes can exploit its multicasting capability and so there is not difference between the two multicasting approaches. Instead, increasing in GS, likely increases the probability to get usefulness in the employment of network layer multicasting; so, the overlay efficiency tends to decrease. Anyway, when the GS becomes large enough, the same reasoning performed for the increase in coverage range may be repeated and the efficiency comes back to increase and reach one for GS=N.

Fig 7-10 show this behaviour and it can be noted that among the considered values for GS the efficiency minimum is obtained for GS = 5.

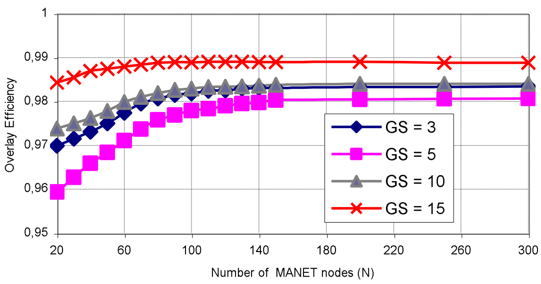

Figure 9– Efficiency of the overlay multicasting of for coverage range R =250 m and FS mobility model, varying the number of nodes N and the multicast group size GS

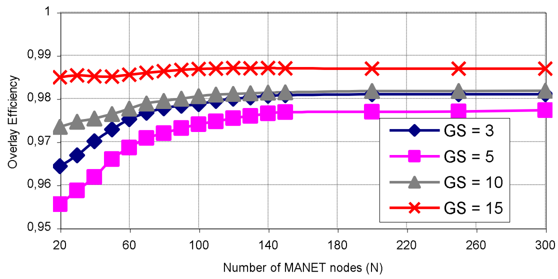

Figure 10- Efficiency of the overlay multicasting of for coverage range R =250 m and MN mobility model, varying the number of nodes N and the multicast group size GS

VI. CONCLUSIONS

In this paper we investigated on the effectiveness of overlay multicasting in MANET without accounting of any network impairments, a part from radio coverage. We measured the ratio between the costs of the distribution tree in case of network layer and of overlay multicasting. We considered this ratio as the *efficiency* of the overlay multicasting. For the construction of the distribution trees we recurred to the TM algorithm [9], in case of network layer multicasting, and to the PRIM algorithm [8], in case overlay multicasting.

The outcoming numerical results showed that, due to the high number of nodes (N) required in a MANET to obtain a reasonable probability of connection among the multicast participants, it is likely that different overlay links will insist on different network paths. This occurrence avoid the network nodes to be stressed by more than one overlay link and yields the efficiency of the overlay multicasting to be always above the 90%. Moreover, the overlay efficiency is an increasing function of the number of MANET nodes and of the device coverage range (R). Anyway, that increase tends to saturate to values that may be less than one. These saturation values depend on the multicast group size. This dependence leads the efficiency to be equal to one in the extreme cases of group size (GS) equal to 2 and N, while for middle values the efficiency behaviour gets a concave up form.

Due to the small loss in efficiency and to the foresee simplicity in managing application layer multicasting, as future work it is worth to investigate if that simplicity yield a kind of system robustness able to cover the performance gap between application and network level multicasting.

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