Impact Analysis of Hierarchical Transitions in Multi-hop Clustered Networks

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***Abstract*—Nowadays, the existing myriad of wireless capable devices has led to the development of numerous multi-hop routing protocols. In particular, due to the scale of these networks, routing protocols with well defined hierarchies have been proposed. By defining different size scenarios with twenty different possible transitions in hierarchies for 2, 3 and 4 clusters, the impact of using such mechanism is evaluated. Simulation based results are presented for 2 different routing protocols showing that a Deferred Routing approach is able to successfully handle hierarchical transitions, delivering up to 4.5 times more data traffic than the remaining protocols, while maintaining a lower overhead. These results motivate the further utilization of such scheme for future large scale wireless networks.**

I. Introduction

An increasing dissemination of wireless capable devices has promoted a generalized connectivity of users to a myriad of services. However, in a near future, users are expected to own several hundreds of gadgets requiring wireless connections [1], demanding a considerable amount of physical resources from the existing infrastructures which may not be available.

In order to cope with the limitations of existing infrastructures, or even with non-existing infrastructures in certain scenarios (e.g. rural areas), the concept of ad-hoc networks has been proposed, allowing the creation of wireless multi-hop networks, where each wireless node behaves as router. Even though these networks may be very promising in the future, especially for local sharing of data, they typically need to handle user mobility and to scale efficiently.

The existing literature on this topic shows that the usage of clusters or routing hierarchies can efficiently keep a multi-hop ad-hoc network scalable. For instance, and regarding the Optimized Link State Routing (OLSR) protocol [2], this issue has been addressed by proposing special Topology Control (TC) messages and hierarchical architecture [3] [4]. While these mechanisms are capable of reducing the total amount of routing information in their own way, the only routing scheme that employs them all is Deferred Routing, recently proposed in this area. However, the impact of such approach must be assessed, in order to determine whether it is beneficial or not to the overall routing scalability. This paper provides a novel assessment approach of the Deferred Routing protocol's performance, analysing how it behaves when node transitions occur in its hierarchy.

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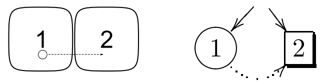
In Section II a background on hierarchical routing is provided, presenting the overall idea behind the concept of Deferred Routing and how the network is organized. The description of a routing evaluation for a hierarchical protocol is provided in Section III, defining relevant scenarios to thoroughly assess both scalability and traffic performance. This section is followed a simulation analysis presented in section IV. Finally, in Section V, the concluding thoughts on this work are presented.

II. Background and State of the Art

Regarding the existing work on multi-hop wireless networks for future wireless communication, a number of routing schemes already exists using different approaches such as proactive or reactive route establishment and even hybrid approaches. Proactive routing protocols for these networks were inspired by the typical protocols used in wired networks, based on the periodic exchange of update messages in order to maintain the routing tables.

As an alternative to the expensive periodic update of proactive routing schemes, reactive protocols were introduced, performing route discoveries on-demand and avoiding the waste of resources experienced with proactive solutions. This approach seems more suitable for mobile ad-hoc networks, where topology changes occur constantly. However, on-demand solutions suffer from an initial delay on retrieving a routing path which may not be acceptable.

The "Deferred Aggregated routing for Scalable ad-Hoc networkS" proposal (DASH) [5] uses both clusters and a well defined hierarchy for scalable routing, while maintaining a virtual view of the network. This approach assumes that each node will solely keep detailed information about its own cluster, and will maintain aggregated information about the network according to a pre-defined cluster hierarchy, allowing smaller and more stable routing tables. Routing decisions are cluster-based, being postponed to further clusters in the hierarchy if necessary, without previously knowledge of the



(a) Cluster View (b) Hierarchical View

Fig. 1. Same Level Transition Example

entire path taken. Even though this scheme may simplify the routing process, whenever a node changes its cluster, the hierarchy needs to be updated side-by-side with the routing table. In this paper the impact of node mobility between different levels of DASH hierarchy will be analysed.

The DASH protocol employs the Deferred Routing approach which can shortly be explained as a routing procedure where nodes postpone routing decisions by forwarding traffic to appropriate gateway (Gw) nodes. This occurs when nodes lack the necessary information to reach a destination (i.e. nodes outside their own cluster), choosing the existing Gws to forward data between clusters, ensuring that this data is received by nodes progressively closer to the desired destination. The choice of the Gw is known since a Gw knows to which clusters it has connectivity with, through its hierarchy.

Similarly to everyday routines, such as driving, the Deferred Routing scheme chooses paths towards gateways as a driver chooses highways from one landmark to another until the final destination is reached. In fact, instead of thoroughly analysing all the existing paths in a very accurate map, a typical and easy solution is to simply drive towards well known and marked areas, such as capitals, important cities, regions or even countries. These landmarks act as gateways for the driver, and throughout the journey, more and more detailed information will be available on the road signs when the driver gets closer to a desired destination.

Taking into account this everyday routing approach, adapting it to computer networks is straightforward and allows a significant improvement in routing performance when compared with typical routing approaches for wireless ad-hoc networks. Moreover, this scheme limits the impact of node mobility, as it relies on condensed views of the network, such that a node moving from one cluster to another (a cluster can be seen as a city or region in a map), will not impact someone travelling from a more distant cluster (corresponding to a country).

By adapting OLSR for intra-cluster routing, the DASH protocol employs the Deferred Routing scheme with the definition of a network hierarchy where different network views exist. A binary tree hierarchy is defined with the assignment of Cluster IDs (CID) to each cluster and by creating "virtual clusters" which represent different granularity levels of the existing clusters. This hierarchy mimics a typical road map, where a cluster can be within different virtual clusters with different levels of detail, similarly to a map which has countries, regions, cities, quarter blocks, and so on. This allows the optimization of a routing table, keeping more concise information about distant clusters, and being more resilient to node mobility, since nodes changing clusters will not render any changes to most of the nodes' routing tables, as they only keep aggregated views of the network. Only neighbour clusters are affected by the addition or deletion of a node in their brother cluster, reducing the normal overhead of such an operation.

III. Routing Evaluation

The overhead issued by a routing protocol has an important impact on the overall performance of the protocol. In fact, a protocol can be considered scalable if its overhead does not increase significantly with the network size. However, routing protocols which handle the network in a flat un-clustered fashion, such as the OLSR protocol, do not usually scale and even protocols with flat but clustered views of the network, may suffer from costly overheads when handling routes between clusters and usually rely on cluster-heads responsible for bearing this burden. On the other hand, routing protocols that manage a network using a hierarchy for clustered nodes, require a lower communication overhead in order to maintain their routes.

While hierarchical organisations may reduce the overall routing overhead, keeping a hierarchy updated may introduce additional overheads, resulting from additional mechanisms such as dynamic addressing [6] or even the update of the nodes position in the hierarchy. While the hierarchy presented by Deferred Routing aims at avoiding similar overheads and resorts to a virtual aggregation of the existing clusters, the impact of nodes moving across distinct clusters still needs to be evaluated.

A. Scenarios Specification

Bearing in mind that the DASH Routing protocol is cluster-based and that it uses the OLSR protocol for intra-cluster routing, the differences between these two protocols will only be noticeable in a network with at least two clusters. Thus, three different scenarios with 2, 3 and 4 clusters were defined. These scenarios will allow the evaluation of the impact of node mobility between clusters on the routing performance. In particular, since the DASH protocol has a well defined hierarchy, a node moving to different clusters will trigger a hierarchical transition and, therefore, the impact rendered by different transitions must be assessed.

In each of the defined scenarios a single node moves between two different clusters, where each cluster has a total of 49 nodes, deployed using a Poisson Point Process over the plan. It starts by being stationary for 250 seconds and after that it will move in the direction of a destination cluster at a speed of $12km/h$, similarly to travelling by bicycle or walking [7], travelling a total distance of 600 meters. Since the purpose of this work is to evaluate the performance of the Deferred Routing protocol, the moving node will also be the destination for a constant bit rate flow of 32 $kbit/s$ (8 packets per second) and all the remaining nodes are static. This type of traffic flows is representative of typical interactive gaming, simple file transfers or information exchange [8], which are all well suited applications for mobile ad-hoc networks.

By specifying a moving node which is part of a traffic flow while keeping all the other nodes static, a more accurate

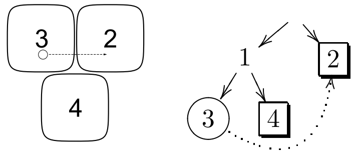


Fig. 2. One Level Transition Example

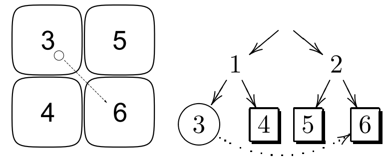


Fig. 3. Two Level Transition Example

understanding of the impact of different level transitions will be obtained. This will reveal how efficiently a routing protocol is when updating its existing routes, allowing not only the analysis of its scalability, but also overall routing performance regarding delivered traffic.

1) Two-Cluster Network: The most straightforward hierarchy in DASH is found in a network with two clusters. In this hierarchy the only possible transitions will occur in the same hierarchical level (0 Level Transition), when nodes move from the cluster with CID 1 to CID 2 and vice-versa. Figure 1 shows the configuration of such network, where the fully circled CID and the end of the arrow respectively correspond to the origin and destination clusters. Since there are two possible transitions, this scenario was simulated twice, one where the node moves from cluster 1 to 2 and vice-versa.

In this scenario all the clusters are affected by any occurring transition since they are sibling clusters. However, in a scenario with more clusters this will not always occur, as shown for the three-cluster network.

2) Three-Cluster Network: As the number of clusters increases in a network, so does the number of possible transitions in the Deferred Routing hierarchy. In a network with three clusters, in addition to Same Level transitions between clusters 3 and 4, there is also a One Level transition between CIDs 3 or 4 and 2. Figure 2 depicts a One Level transition, from cluster 3 to 2. Moreover, in order to better illustrate the Deferred Routing behaviour, in these figures the clusters which are affected by each transition, in addition to the source and destination, are depicted in a shaded box. This highlights the existing aggregated views used by DASH, such that for Same Level transitions nothing is changed for nodes in cluster 2.

Since there are three clusters in this scenario, six different transitions may occur - from cluster 3 to 4 and 2, from cluster 4 to 3 and 2 and finally from cluster 2 to 3 and 4. Similarly to the previous scenario, all these transitions were individually simulated, leading to four One Level transitions and 2 Same Level transitions.

3) Four-Cluster Network: In a network with a total of 4 clusters, Two Level transitions may occur when a node changes its cluster association to a cluster in a different branch of the network. Even though Same Level transitions still exist, One Level transitions will never occur, since a node moving to a non-sibling cluster will have to go one level higher into the hierarchy and then lower to a leaf cluster. In Figure 3 a Two Level transition is presented, where a node from cluster 3 moves to cluster 6, affecting not only the source and destination clusters, but also their sibling brothers. This transition represents the worst case scenario, since Same Level transitions only affect 2 clusters. This reduced impact is related with the adoption of the Deferred Routing concept, where in a network with 4 clusters each node perceives only 2 clusters.

Once again, since several transitions among the four different clusters exist (12 possibilities), this scenario was simulated individually for each transition, leading to a total of 4 Same Level transitions and 8 Two Level transitions.

IV. Routing Performance and Results

In order to achieve a complete analysis of the routing performance protocol an study through simulation is presented. This will provide a better understanding of the protocol, taking into account aspects such as wireless interferences and node mobility.

A. Simulation Results

Regarding the performance of the DASH protocol and its hierarchy in the presented scenarios, simulations have been carried out using the OPNET simulator, with a total of 30 runs per scenario, always using different seed values, for a total simulated time of 15 minutes. The considered wireless nodes follow the IEEE 802.11g standard [9], and have a maximum range of 100 meters (Transmit Power of $3.7e^{-4}W$), which corresponds to the maximum obtainable range of common wireless cards [10]. However, due to the accurate radio model implemented by default in the OPNET Simulator, asymmetric links or even unidirectional links may occur, as well as channel errors and multi-path interferences respectively. All other simulation parameters not mentioned here use their values set by default in the OPNET Modeler Wireless Suite Simulator, version 16.0.A PL1.

The simulations of each scenario were performed using not only the DASH protocol but also OLSR. Moreover, the obtained simulation results have a 95% confidence interval calculated from the central limit theorem.

1) Average Number of Forwards per TC: As previously stated, any protocol using a routing scheme resembling to OLSR should minimize the average number of forwards per topology control message, avoiding an expensive flooding of routing messages. As it is possible to see in Table I, in a smaller network with only two clusters the OLSR protocol performs worse, having a higher average number of TC forwards.

While for a two cluster network only Same Level transitions were possible, for a three cluster scenario One Level transitions will also occur. Even though in theory no change should

TABLE I
SIMULATION RESULTS

		Two Clusters	Three Clusters		Four Clusters	
		Same Level Transition	Same Level Transition	One Level Transition	Same Level Transition	Two Levels Transition
Forwards per TC	OLSR	75.84	115.78	115.82	161.72	161.69
	DASH	34.54	34.34	34.41	34.53	34.51
Losses	OLSR	87.90%	92.46%	93.18%	92.42%	94.67%
	DASH	19.35%	41.21%	33.32%	22.57%	23.27%

be registered between these two transitions, the results reveal that the OLSR protocol, as predicted, increases its number of forwards while the DASH protocol has a constant number for both transitions and even when comparing to a two cluster network. This steady value registered by the DASH protocol reveals its scalable properties, whereas the OLSR protocol shows why it does not scale, registering more forwards through simulation than what would be expected.

The higher number of average forwards through simulation when compared with the theoretical results reflects one of the major problems with the MPR selection process. While a certain number of MPRs is expected for a well behaved network, in reality, and even through simulation, the volatility of the wireless links renders the task extremely complex, particularly in bigger networks.

In a four cluster network, the OLSR protocol registers a significant climb in the number of forwarded messages. In fact, only DASH remains stable, as shown in Table I.

2) Routing Traffic Performance: Even though the scalable properties of a routing protocol positively influence the overall traffic performance, it is important to analyse aspects such as the percentage of losses or the end-to-end delay. In Table I the percentage of registered losses for each scenario is presented, revealing that the DASH protocol outperforms OSLR.

V. CONCLUSION

The Deferred Routing scheme has been proposed as a new routing approach where a well defined hierarchy is used in conjunction with an aggregation of network clusters into virtual clusters. While such routing conception may reduce the typical routing overhead found in a network, the impact of node mobility among different hierarchical levels could influence the overall performance of the routing protocol. By defining three different scenarios with a total of twenty different transitions in the Deferred Routing hierarchy, an evaluation of the DASH protocol was performed, comparing its results with the OLSR protocol.

The obtained simulation results revealed that, as the number of nodes in the network increases, the worse the performance of the OLSR protocol gets, registering more forwards than what would otherwise be expected. It is important to note that, only one node has mobility in order to pragmatically infer on the protocols scalability, while assessing their routing robustness while the destination node keeps changing position. Moreover, exactly the same conditions are used for both protocols, where not only did the DASH protocol reveal itself as being more scalable, it also achieved a considerably better performance regarding data traffic delivery, having less losses.

The obtained results suggest that Deferred Routing can be a viable solution for routing in future large-scale wireless ad-hoc networks, keeping its performance stable as the number of nodes in the network increases.

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