Routing Groups in Ambient Networking

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ABSTRACT
In this paper we discuss aggregated mobility patterns and physical proximity of nodes within Ambient Networks, where an Ambient Network can be described as a network that integrates heterogeneous nodes and access techniques. We illustrate how awareness of node mobility patterns can be used to identify groups of nodes moving together, and how this grouping can be used to decrease signaling overhead, for example the signaling associated with a mobility event, and increase transmission efficiency. First, we describe the architectural and naming issues associated with this concept and discuss a number of mobility optimizations that can be applied to these moving networks. Further, we introduce algorithms that can recognize the presence of a routing group to enable the use of routing and mobility optimizations. Finally, we assess the performance and benefits of the routing group approach by means of simulation.

Categories and Subject Descriptors
C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design – *Network communications, Wireless communication*

General Terms
Algorithms, Performance, Design.

Keywords
Ambient Networks, Routing Groups, Mobility.

1. INTRODUCTION
The distinguishing features of future mobile systems will be the way in which the networking infrastructure dynamically organizes itself within a technologically and administratively heterogeneous environment. In particular, the Ambient Networks (AN) [1] approach introduces network composition, i.e. the negotiation and dynamic cooperation between networks as a means to achieve high integration.

In this contribution, we discuss the creation of aggregated structures that we name Routing Groups (RGs), comprising wireless nodes that have similar mobility patterns and other mobility-related requirements. The aggregation may take advantage of existing mobility structures and improves efficiency in transmitting data and/or handling network related procedures such as the handover (HO) between different access points (APs). As an example, multiple users moving together and handing over at the same time between the same pair of access points, may be organized in a routing group so that only a single message (to the RG leader) needs to be exchanged to successfully accomplish the handover procedure. This would replace the dedicated mobility signaling that would otherwise be required for every terminal. In general, this is advantageous provided that aggregation of information is possible for example, if equivalent or similar messages would otherwise follow the same path [2].

The rest of the paper is organized as follows: in Section 2 we give an overview of the Ambient Networks project and the related mobility functional entities. Section 3 explains possible optimizations that the RG structure allows in mobile networks. In Sections 4 we propose two approaches for algorithms that support RG formation in mobile ad hoc mobile**.** In Section 5 we give some results obtained applying the RG concept to a routing algorithm, the Dynamic Source Routing Protocol (DSR) [3]. Finally in Section 6 we conclude the paper.

2. AMBIENT NETWORKS AND MOBILITY CONTROL FUNCTIONS
The *Ambient Network* Integrated Project [1] develops new networking concepts for future wireless and mobile networks. A key aspect of the project is to support dynamic composition of networks to establish a common control layer for various network types. This common control layer enables a more "plug and play" style of internetworking that will enable sophisticated network features, and allow also dynamic business relationships between network providers.

However, the dynamic nature of the network introduces a number of new challenges for mobility support that are addressed by the project. These include operation over diverse link layers, mobility support across differing administrative and technology domains, and the need to provide with mobility management for a variety of different mobile endpoints, from user devices, through to applications, to groups of nodes moving together. The mobility architecture developed by the project integrates existing mobility mechanisms into a toolbox that can be configured to use particular mobility mechanisms based on the type of endpoint that is moving, and the capabilities of the network.

The mobility related aspects of the Ambient Networks architecture has the following key concepts: First, the identifier of an endpoint and its locator can be split such that the identity is no longer tied to the point of attachment to the network, which is similar to the concept proposed in [8]. Second, since there are several mobility techniques and solutions in existence, each of which supports optimizations for particular environments where they may be deployed, the architecture allows mobility tools to be selected on-the-fly. This selection takes several aspects into account; including device and network capabilities, operator policy, and the handover requirements introduced by the mobility endpoint.

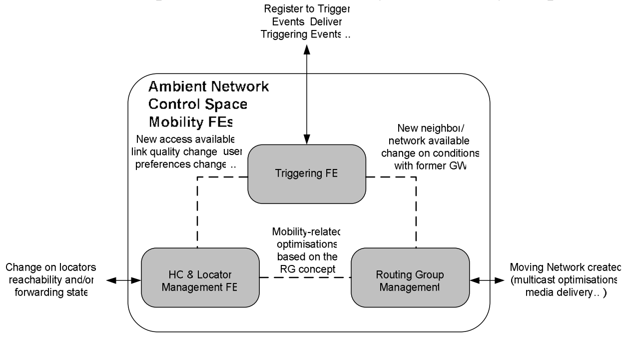

Figure 1: Mobility Architecture in Ambient Networks

The mobility related components of the architecture is shown in Figure 1 and includes three different functional entities: The 'Triggering FE' (TRG-FE), the 'Handover and Locator Management FE' (HOLM-FE) and the 'Routing Group Management FE' (RGM-FE) and the associated internal and external interfaces between them.

The TRG-FE manages triggering events related to mobility, collecting, classifying, filtering and finally delivering them other Ambient Network FEs where they are used to initiate a suitable response. The number of triggering events handled by the system and the recipient of these events is configurable, thus offering a very flexible and dynamic framework for trigger delivery, both within a device and also across a network.

The HOLM-FE includes all the mobility management protocols and related mechanisms needed to manage locator updates of a mobility endpoint as it changes its point of attachment to the network. It provides a framework for a flexible toolbox which can easily integrate and make use of new and existing protocols. This is essential given the wide range of network characteristics and capabilities supported by Ambient Networks.

Finally, the RGM-FE implements algorithms and functions to detect a group of mobile nodes which are in each other's proximity, and follow a common mobility pattern. The establishment and maintenance of a routing group enables a number of optimizations once the group has been formed and agreed to cooperate based on the means of network composition. The following advantages can be mentioned:

- Internal routing; as will be seen later in the paper, the knowledge about network topology that is associated with RG formation can be beneficial in terms of optimised routing between members of the routing group
- Mobility optimisations; by managing the whole RG as a single entity, it is possible to reduce the overhead associated with mobility-related events, for example, by aggregating handover signalling, etc.
- Delegation of Mobility Responsibility; nodes may rely on others to perform mobility actions on their behalf, enabling mobility support in scenarios where a device may not support the required mobility solution
- Tailored Election of Gateways may additionally help to balance load within the RG and provide optimized behaviour

The following section provides a more in-depth description of the different RG detection and formation approaches for accomplishing the following problem areas: (i) Detecting when devices share a common mobility pattern, for example, if the devices are all on-board the same train. (ii) Determine how long devices are likely to be in range of each other in order to predict the stability of the RGs to be created.

The structure of the RGs is expected to contain at least one gateway device that peers to other networks and provides connectivity to other devices within the RG. This setup introduces challenges related to the locator management; a node may require two simultaneous identifiers, one to communicate within the RG and another for external communications. In certain cases, however, these locators can be identical.

The external locator may be assigned by different entities, according to the routing group mobility mechanism being used, as discussed later in the paper. However, the internal locator may be either topologically independent or dependent; in the former case it can be derived from some global node identifier (MAC address, HIT, etc), whilst in the latter case some entity within the RG (probably the gateway) announces a prefix which devices use to automatically generate an internal locator. When more than two gateways are present in the RG (multihoming), automatic locator generation is more challenging because the nodes may be required to manage multiple locators concurrently.

Last, but not least, changes to locators after a mobility-related event may trigger multiple instances of the mobility management signalling. The use of signalling aggregation and delegation of mobility handling to a gateway device means that the RG structure helps to optimize handover of the network. These mobility optimisations are discussed further in the next section. Mobility of the RG has to be tailored to the specific solution/protocol being used, but the design is flexible enough (through the mobility toolbox concept) to allow the use of different solutions. Network Mobility (NEMO), Host Identity Protocol (HIP) and Mobile IP (MIP) are among the ones being considered in the project [8],[9].

3. ROUTING GROUP MOBILITY

To illustrate in more depth the optimizations enabled by the creation of a routing group, this section provides more detail on the different aggregated mobility approaches that are enabled by RG formation. The mobility optimizations need support both within the routing group, and potentially deeper into the fixed network where Routing Group Support Nodes (RGSNs) may be needed to implement parts of the mobility functionality (one example is a Mobile IP home agent). Support within the RG is likely to be provided by a 'specialist node', such as the mobile router (MR), which peers the RGs to external networks. The most important candidate RG Mobility Functions for handover optimizations [7] identified by the project are described next. Note that there are multiple deployment options as to where in the network to support these functions.

Local Signalling Proxy: When locator change occurs, a node may need to update relevant information with some correspondent nodes and or with location directories. Updating locator information for a RG node could result in a large number of uncoordinated messages. Therefore the node may delegate this task to a local proxy node.

Remote Signalling Proxy: This function solves the same problem as the previous one but an additional optimisation could be achieved by delegating the locator change update to an RG external node located in the wired infrastructure.

Route Optimisation: When a RG changes location, the route(s) towards and from Correspondent Node (CN) may become inefficient. Sharing some additional information between forwarding nodes may result in a shortcut between RG and CNs.

Signalling Compression: When the RG sends locator updates, the individual messages may include a huge amount of redundant information which could result in a bottleneck on wireless backhaul links. Depending on the specific protocol to be chosen, message compression could significantly reduce the amount of traffic. This function is an alternative approach to the signalling proxy functions.

Mobility Anchor Support: Traffic forwarding between RGs and CNs can be achieved via Mobility Anchor Points. The anchors are used to encapsulate and forward data packets to another anchor point or the final destination. The anchor points represent fixed forwarding points and can aggregate all RG packets in upstream or downstream direction in one single logical forwarding tunnel.

The advantages of introducing these functions include:

- Improvement in scalability and performance of simultaneous handover of large amount of nodes: they will be handled as one moving RG. A simultaneous handover for a large number of nodes may require many location update messages to be generated at the same time. As a consequence some networks (e.g. like a RAN) may be flooded with signaling messages and the handover latency could significantly rise for the nodes of the RG..
- The ability for nodes to delegate mobility management to third party nodes in the network, e.g. a MR. The key difference here to non AN scenarios is that nodes may actively choose whether to handle their own mobility or whether to ask a (trusted) 3rd party to manage it for them.

4. RG FORMATION

We present two example algorithms designed to create and maintain RG structures. The first one operates in a distributed manner, where network entities discover neighboring devices and assess whether these nodes will be stable neighbors in the future. On the other hand. the second one uses intelligence in the network to detect stable neighbor devices and indicate to them that routing group formation is possible and could be indeed seen as a trigger for the distributed one, so as to avoid the extra overhead in those cases in which this is not necessary.

4.1 Aggregation Willingness Approach

This section briefly describes the *aggregation willingness approach.* A more complete explanation and investigation is available in [4]. The algorithm operates by obtaining stability information from periodic neighbor device monitoring, i.e., terminals transmit HELLO packets to communicate their status as well as their stability beliefs to other nodes [10]. The algorithm uses local information only, i.e., every node monitors and communicates only with its one hop neighbors (nodes within its radio range). Therefore RG decisions are made based on a local knowledge of the network which makes our solution suitable for highly dynamic and energy constrained networks. The stability is calculated based on neighboring sets using the presence of communication links over time, where a link is assumed to be up whenever the reception of a HELLO packet is successful. In addition, stability beliefs at different nodes are exchanged between neighboring devices to refine their local views in the attempt of making better decisions. This approach is fine grained with accumulating a number of stability beliefs, which are periodically monitored for every node in range. This approach does not need knowledge of the link quality (e.g. BER, RSSI), therefore is suitable even for resource limited terminals that, due to their hardware constraints, can not estimate link qualities.

The periodically transmitted HELLO packets contain information related to the status of a given node and, in particular, to its measured stability metric. These packets are exchanged through broadcast channels without coordinating the transmission between nodes. This makes the scheme highly practical but also introduces some problems related to packet collisions, in fact at high traffic load this mechanism could be inhibited by the interference introduced by transmission of data packets. At a given user, we define a neighboring device as stable whenever it was within communication range for a sufficient amount of time. In fact, if this is the case, the device will likely remain within range in the future as well and it would make sense joining these nodes in a RG. Observe that physical mobility in everyday life is often correlated. In this case, it is sensible gathering neighbor information in order to assess which neighboring nodes are members of the same mobility group.

4.2 Infrastructure-Aided RG Detection

In contrast to the previous fully distributed approach, the *Cell-Based Triggering (CBT)* algorithm relies on intelligence in the network infrastructure to detect stable neighboring nodes. This has the advantage that no periodic neighborhood scanning is required, thus reducing the energy cost associated with distributed approaches where nodes have to transmit discovery packets periodically, and furthermore, their reception circuits have to be active most of the time.

The CBT algorithm assumes urban environment where each Mobile Node (MN) has connected to the cellular infrastructure by default. With the help of the cellular infrastructure, it is possible to pre-identify the presence of the RGs, as detailed in [7]. The CBT algorithm runs in the Base Stations (BSs) and detects aggregated movements of MNs by analyzing the HO events generated by them: If a set of MNs is moving together, some of them are expected to perform HO between the same two BSs. The CBT algorithm detects this and triggers the affected MNs which then execute their built-in (arbitrary) distributed mobility clustering algorithm (e.g. the one that has been presented in the previous section) in order to verify the 'guess' and to perform the necessary operations, e.g. create the RG. Since MNs are triggered only if they are identified as having a good chance to form a RG, and the fact that the number of RG members is usually very small compared to the total number of MNs in a network, this approach reduces the number of the expensive neighbor scans dramatically, see [7] for more details. In this paper we extend the CBT approach described in [7] by enabling the detection of slowly moving and static groups also. In the next we detail the CBT algorithm.

For *moving MNs*, assume that MN A performs a HO from BS_1 to BS_2. As a response to the HO event, the following steps will be executed.

1. BS_2 registers the new MN A. Since A handed over from BS_1, BS_2 identifies the set of MNs S_1 which are all handed over from BS_1, and are currently associated with BS_2. If $|S_1| \geq 2$, then execute step 2.
2. BS_2 sends S_1 to BS_1; BS_1 identifies the set of MNs $S_2 \subset S_1$, where all MNs in S_2 had been simultaneously associated with BS_1 for a given (arbitrary) period of time, and sends back S_2 to BS_2. The MNs in S_2 (if any) are identified as a potential moving RG and BS_2 will send triggers to them for executing the local distributed RG-formation algorithm

In order to identify the slow-moving or static MNs, our extension to the CBT algorithm performs the following procedure.

Determine the set of MNs at cell k

$S_3^k := \{MN_i : t_i > T_k + \varepsilon, \forall MN_i \in BS_k\}$, where

$T_k = \min(\overline{T}_k + \overline{T}_k^{\alpha}, \hat{T})$

If $|S_3^k| \geq 2$, then trigger the MNs in S_3 to execute their built-in distributed RG formation algorithm.

Here t_i is the time period for which MN_i has been staying in the cell already, $\overline{T}_k$ is the average time the MNs have spent in cell k in total (cell holding time), $\overline{T}_k^{\alpha}$ is the confidence interval of the cell holding times with confidence level of α.

As an explanation, the resulting set of MNs S_3 will include those MNs that stay in the cell for a time period longer than the average with high probability (we set $\alpha = 0.95$). Note that in case of a rather static scenario where the average cell crossing time $\overline{T}_k$ would be very high, we maximize the gap between triggers by $\hat{T}$ for each MN.

In the following we present results of the performance study of CBT. Figure 2 shows the average size of the RGs where all RG members were triggered by CBT.

Note that for lower network density (MNs≤75) the effect of $\hat{T} = 20\text{s}$ is visible on the curves (all RGs reach their target size latest by that time). However, for larger number of MNs the cells experience some faster MNs passing by, with high probability; these cells set their $\overline{T}_k$ to a value lower than $\hat{T}$, thus the associated MNs will be triggered more frequently, not having to wait until $\hat{T}$.

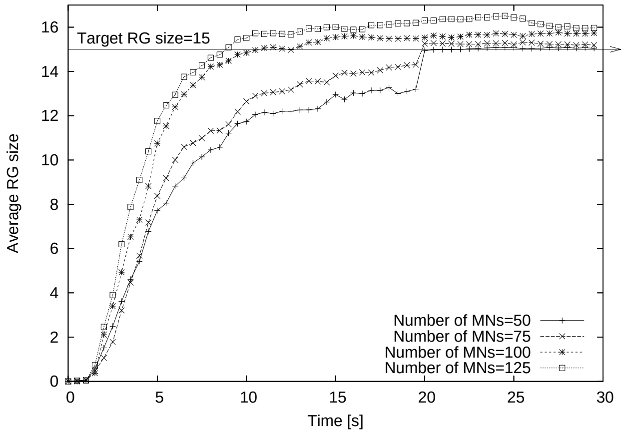

Figure 2: Development of RGs triggered by CBT. Target RG size was (arbitrarily) set to 15, and $\hat{T} = 20s$

Table 1 shows the number of events generated by CBT. The values are average for each terminal for a 100s time period.

MNs	Triggers	RG setups	Ratio
50	2.31	0.96	41.45 %
75	4.36	1.36	31.17 %
100	6.48	2.29	35.43 %
125	7.84	3.24	41.26 %

Table 1: Average number of events produced by CBT for each MNs [1/100 s]

The table shows that the 'guesses' of CBT to pre-identify RGs are very good: There are only 35-42% more triggers than the perfect solution (i.e. where each trigger would actually lead to a successful RG formation), and meanwhile the RGs collect all of their members in a reasonably short time.

5. BENEFITS OF THE RG CONCEPT

In the following section, we prove the effectiveness of the Routing Group approach by focusing on a rather general multi-hop wireless network and exploring the performance of a generic RG-aware path discovery and routing scheme. First, we describe the reference scenario used to carry out the performance evaluation, then present the RG-aware routing strategy. Finally, we discuss the performance of the considered approach, by highlighting the advantages offered by the RG paradigm.

5.1 Simulation Scenario

We consider an infrastructure based wireless network composed by fixed Access Points (APs) and mobile users. Devices move within a square area of 100 x 100 m^2. To test the distributed RG algorithm and the benefits it can introduce in routing, we developed a novel mobility model [5] to allow group mobility behavior. We account for one AP and 20 mobile nodes, five of which behave according to a group mobility pattern. The remaining 15 devices are characterized by an independent mobility behavior (*isolated users*). User speeds span between 0.5 and 2.0m/s in order to mimic a typical pedestrian scenario. Isolated users are, on the average, uniformly placed within the simulation area, whereas the average distance between any two users in the mobility group is about 10 m. The AP is randomly placed within the mobility area. All entities exchange data using an IEEE802.11b wireless technology since it has a good transmission range (i.e. about 60 meters), whereas RG discovery and maintenance is achieved through a dedicated low power and low range radio, e.g., IEEE802.15.4. Both single and multi-hop routing is permitted as this allows transmission even if the node is not in the transmission range of the AP.

Next, we describe a possible RG aware algorithm to perform routing in multi-hop wireless environments. Due to the distributed and multi-hop nature of the scenario, we decided to use the well known DSR (Dynamic Source Routing) scheme [3]. This scheme was adapted in order to incorporate the moving group knowledge into the DSR procedures. In the following, we briefly review the DSR protocol by subsequently detailing the proposed modifications.

In order to include RG awareness into the aforementioned algorithms we proceed as follows. First of all, we assume that all nodes in an RG run the distributed willingness-based RG discovery mechanism proposed in Section 4. Further, we dynamically elect, within each RG, an RG leader which corresponds to the best suitable user. That is, we assign a weight to each mobile device. The weight is based on the node's own properties which include residual energy, associativity, and/or type and number of available radio technologies. How weights are assigned is beyond the scope of the present analysis and does not affect the validity of the concepts that we will demonstrate in what follows.

The RG leader is the only device in the RG in charge of the route discovery (RD) procedure. As a follower needs to find a route to a destination, it directly unicasts the data to the RG leader. On receiving the data flow, the leader starts the discovery procedure by means of a standard DSR RD. Also, in order to limit and optimize the amount of control traffic (signaling overhead) only RG leaders and isolated nodes re-broadcast the Route REQuests (RREQs). In case multiple nodes in a group need to communicate with the same destination, they all refer to the RG leader as the relay for their respective transmissions. Hence, the RG leader is the only device which activates a RD procedure, by therefore limiting the control traffic with respect to standard DSR, where a single RD is activated for each RG member. This, for instance, may be the case where all followers need to reach an AP to get to the fixed portion of the network. This can be seen, as in standard clustering algorithms [11] for ad hoc networks, as a way to partially centralize the transmission control thereby enhancing the performance.

The RG discovery and maintenance algorithm is as described in Section 4. We refer to T_H as the transmission period. Every device sends, on average, a HELLO every T_H second. We now introduce two further parameters, T_{SCAN} and W: T_{SCAN} is the time period (also referred to as SCAN period) considered to check and update the stability measurements (stability beliefs) from the statistics indicated in the HELLO packets received, whereas W is the *"window"* or the maximum number of past stability measurements (HELLOs) to be memorized by a user for any of his neighbors. The parameter values used are: 12 s for T_H, 30 s for T_{SCAN}, 4 for W and finally we set the transmission power group members at 1% of typical IEEE802.11b's power (the minimum allowed).

We observe that the above scheme consists of a *slight modification* to the standard DSR. However, in spite of this and as will be shown in the next section, the obtained results are dramatically different from the ones obtained with the standard DSR approach. This proves that even a localized and limited information about aggregate mobility behaviors has a strong and, in general, beneficial impact on the performance.

5.2 Results Discussions

We report the results obtained for the above scenario, by considering both the RG-aware routing algorithms and standard DSR. These have been derived using an internally developed simulation tool [5], which considers a quite detailed propagation model and implements a mobility model [4] that allows the simulation of group mobility behavior. The communication within the standard (mobility unaware) DSR operates at the maximum power level. Instead, the RG-aware solution allows for a reduction of the data transmission power between members of the same RG since they know that they are strictly close to each other and therefore they can set an ad hoc level of power in transmission (i.e. the one that allows a good packet error probability in the associativity algorithm range of work). Henceforth, the group mobility awareness allows implementing *topology control* algorithms at almost no expense. This leads to a diminished interference which translates into a higher system capacity.

Quantitative results are obtained by considering 100 independent simulation runs for each point in the graphs. Each run lasts for 10 minutes of equivalent simulation time. Performance metrics are measured by varying the traffic generation rate (expressed in packets/s) and the number of group members that generate data traffic (*active users*), instead the other send only HELLO packets to maintain the RG structure Active users are interested in getting their data flow to the AP. Different curves are plotted by varying the number of active users (AFX in the figure) in the RG. Both the RG-aware (DSR-RG in the graph) and the standard DSR (DSR in the graph) are considered. The same notation will be used for all figures reported in this section. In Figure 3 we report the trade off between total energy expenditure (including transmission and reception costs for all nodes) and throughput performance by varying the packet generation rate. As clearly depicted in this figure, DSR-RG is always superior in terms of total energy expenditure. More than this, the advantage increases with the number of active users in the RG. With a single active user the energy expenditure is slightly improved but the throughput performance is better for the DSR case. This is trivially due to the extra hop needed to selecting the RG leader as the relay node for the transmission. However, as the number of active users becomes larger than two, DSR-RG outperforms DSR for both metrics.

One of the main reasons of this behavior is the less level of interference in the network that each user makes in order to run independently his own routing scheme (i.e. his own RD), as depicted in Figure 4. Clearly, the signaling traffic of DSR-RG is almost independent of the number of active users, whereas in DSR the same metric considerably degrades with an increasing number of communicating devices.

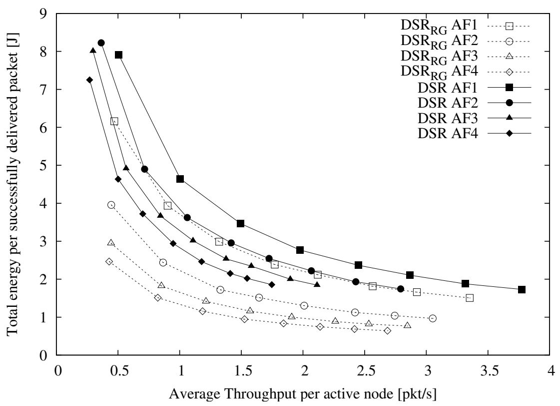

Figure 3: Total energy expenditure vs. Throughput by varying the packet arrival rate

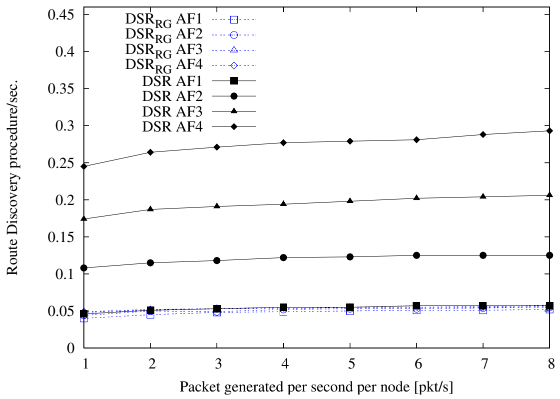

Figure 4: Average number of Route Discoveries per unit time

6. CONCLUSIONS

This paper describes the current on-going work within the Ambient Networks project related to aggregated mobility patterns and the formation of routing groups. It highlights the architectural implications and advantages of creating such routing groups, and introduces two novel algorithms for detecting and creating routing groups out of a set of mobile devices.

The first algorithm is distributed, and selects stable neighbor devices through the use of periodic broadcast messages. This algorithm is suitable for highly dynamic environments, where there is no assumption of nearby infrastructure nodes. The second approach relies on intelligence in the network to detect neighboring nodes and initiate routing group formation, but reduces the signaling overhead within the group, as far as it will only trigger a distributed approach, when it gets enough evidence that the nodes are actually moving together.

The paper has also shown the benefits that the RG concept may have over traditional ad hoc routing protocols in mobile networks, being able to reduce the overhead as well as the corresponding energy expenditure, especially on Routing Discovery procedures, by exploiting intrinsic topology awareness.

Subsequent work is focused on developing these concepts further, fine-tuning the proposed algorithms but also investigating how routing groups and the optimizations that they enable can be integrated into new networking concepts such as the Node Identity Architecture [12], where efficient group mobility and routing optimizations are a key requirement.

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