A New Efficient and Energy-aware Clustering Algorithm for the OLSR Protocol

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Summary

Integrating quality of service (QoS) in a mobile ad hoc network (MANET) is a difficult challenge and a very tedious task. It requires to find a compromise between several QoS parameters. The energy criterion is one of the most important of these parameters that will provide a long lifetime for a given MANET. This paper proposes a new clustering algorithm for the OLSR routing protocol which consumes less energy and enhances transmission delay. This algorithm manages nodes density and mobility; and gives major improvements regarding the number of elected clusters Head. We have conducted some comparison with other clustering algorithms to prove the efficiency of our algorithm. Our main objective is to elect a reasonable number of clusters Head that will serve for hierarchical routing using OLSR as a routing protocol. The second objective is to increase the network lifetime by considering the Ad hoc residual energy when taking routing decisions. We have found that our algorithm optimize the end to end delay by adopting a selective forwarding approach based on the hierarchical routing model

Key words:

Ad hoc networks, routing protocols, QoS, clustering, energy aware routing, hierarchical routing .

1. Introduction

Staying connected anywhere anytime to a network is really the main objective of mobile technologies. Mobile Ad hoc network (MANET) [1] may provide a solution. With MANETs, all nodes are routers and forward packets without need of any infrastructure. This kind of network is spontaneous, self-organized and self-maintained. In this context, routing the data is the big challenging task since many issues are covered: scalability, security, lifetime of network, wireless transmissions, increasing needs of applications.

Many routing protocols have been developed for Ad hoc networks. They can be classified according to different criteria. The most important is by the type of route discovery. It enables to separate the routing protocols into two categories: proactive and reactive. In reactive protocols, e.g. Dynamic Source Routing (DSR) [2] and Ad hoc On-demand Distance Vector routing (AODV [3]), the routing request is sent on-demand: if a node wants to communicate with another, then it broadcasts a route request and expects a response from the destination. Conversely, proactive protocols update their routing information continuously in order to have a permanent overview of the network topology (e.g. OLSR [4]).

Currently there are many routing protocols for each type of network. However, even this efficiency on small and medium size networks, neither of them can be used on large scales because they generate too much control traffic or would require too large routing tables.

One solution commonly proposed for routing is to introduce a hierarchical routing by grouping geographically close nodes. Each group, called cluster, is represented and managed by a particular node called cluster head.

In this paper, we focus on the Optimized Link State Routing (OLSR) protocol [4], a proactive solution which computes in advance routes to every node in the network.

This paper is organized as follows. In Section 2, we give the problem formulation. Section 3 we detail some related works. Section 4 gives an overview of the original OLSR protocol. Section 5 discusses in more detail our clustering proposal, where section 6 shows the obtained results of some conducted simulations. In section 7, we'll discuss impacts of some mobility models on our clustering approach. Section 8 presents performance evaluation and a comparing framework for different clustering approaches. The last section concludes the paper and presents some future work.

2. Problem Formulation

The main drawback of proactive routing protocols like OLSR is that they generate a large amount of control messages that consumes bandwidth and energy of mobile nodes and limits the user data traffic. In the OLSR protocol, each node sends its local view of the network, in form of TC (Topological Changes) messages to others nodes in the network. This can lead to performance and scalability problems when the network size increases. In addition, low capacity devices might find unaffordable to store routes to every node in a very large-scale Ad hoc networks.

Clustering is a well-known technique, highly used within MANETs to alleviate these problems. It is mainly employed to reduce the complexity of proactive protocols by dividing the entire network in small and manageable

areas. Mobile nodes will elect, based on some QoS criteria, a designated node which is called a cluster Head.

In this work, we aim to define a new clustering approach based on the energy criterion that is one of the most important QoS parameters of an Ad hoc network in order to provide a long network lifetime, as well as to reduce energy consumption for ad hoc network, particularly in clustering and routing. The proposed approach aims to enhance the routing process and produces a small number of stable (higher residual energy) clusters Head.

In the literature, several clustering approaches were proposed. They generally differ on the used cluster Head selection criterion. In our proposal, we present a clustering approach that elects a reduced and reasonable number of clusters Head that have a high residual energy. This can prolong the lifetime of the entire network and enhance the routing process.

3. Related Work

The OLSR protocol operates normally within one cluster; with the exception that TC messages are not forwarded by a node belonging to a cluster different from the originator of the message. To reach a node in another cluster, the authors of [5] have proposed a protocol called C-OLSR that creates routes between clusters. This protocol creates two levels of hierarchy in the network and two new messages were added: C-hello and C-TC. Similarly to OLSR, MPR clusters (C-MPR) are selected using C-Hello messages. These messages are used to maintain clusters neighboring. C-TC Messages that contain a list of neighbors are propagated to all other clusters Head via the C-MPR (non MPR clusters that do not transmit messages C-TC).

In [6], authors propose a clustering mechanism for OLSR based on the concepts of forests and trees. The entire network is seen as a forest, where each cluster is considered like a tree and the branches represent the links between nodes. To select a root of the tree, the algorithm uses maximum local connectivity, i.e. nodes having more neighbors are designated as roots. In order to enable OLSR nodes to form and maintain trees, OLSR nodes need to periodically exchange a new branch message in addition to usual OLSR control messages.

In [7], authors propose a hierarchical OLSR version. The hierarchy is built based on nodes' capabilities. The capability of a node depends on the amount and properties of its wireless interfaces. A node with several interfaces and large radio range will be selected as a cluster Head. If the mobile nodes have the same wireless properties, routing will be based on OLSR standard operations and therefore no clustered structure is built. When a network is clustered, a new message called CIA (Cluster Id

Announcement) is periodically sent by cluster Heads to declare their leadership.

In [8], the authors propose an enhanced solution for Ad hoc clustering based on multi hops and network density for the standard OLSR protocol. The cluster is represented by the node that covers the largest number of symmetric neighbors in the cluster.

In [9], we have proposed an enhanced solution for Ad hoc clustering based on network density and mobility for the standard OLSR protocol. The cluster is represented by the node that has a low mobility and covers the largest number of MPR nodes in the cluster.

In this paper, we present a clustering algorithm optimizing the residual energy when electing clusters Head. This method avoids selecting mobile cluster Head nodes with small residual energy that can have a negative impact on the lifetime and performances of the network. Thus, the residual energy criterion will be used as a metric in the OLSR routing standard process. Our proposal has the merit to use only OLSR standard messages (Hello and TC), no new messages were introduced to build the clustering structure.

4. Optimized Link State Routing OLSR

Optimized Link State Protocol (OLSR) [4] is a proactive link-state routing protocol. It is an optimization and adaptation of a pure link state protocol to the context of MANETs. The main idea of the OLSR protocol is the use of Multi-Point Relays (MPR). MPRs are used to reduce the information exchange overhead in the same region of a given network.

Three main components of OLSR are neighbor sensing, efficient broadcasting of control traffic, and diffusing sufficient topological information in the network for the shortest path calculation.

In neighbor sensing, each node periodically sends a HELLO message, containing the information about its neighbors and their link status. A mobile node may obtain topological information up to two hops away. This is used by each node to establish a Multipoint Relay set (MPR set) among its neighbors. A node must select MPRs in a way such that a message transmitted or retransmitted by the MPR set will be received by all two hops neighbors of a given node. To have an efficient and limited diffusion of traffic control, only the selected MPR nodes will participate to broadcasting information in the MANET. To share sufficient topological information in the network, TC messages are used to send information about own advertised neighbors which includes at least the MPR Selector list (The MPR selectors of a node x is the set of nodes which have selected the node x as MPR). This is transmitted to every node in the network through the MPR Flooding process. Then, all nodes in the network will

obtain a partial topological view, describing a subset of links in the network. Based on this topological database, a node can calculate routes based on the shortest path algorithm.

5. Algorithm Description: Energy-aware OLSR clustering

Clustering in MANETs can be defined as a virtual partitioning of mobile nodes into various groups. These groups are built with respect to their nearness to each other's. Clusters in a MANET can be categorized as overlapping clusters or non-overlapping clusters as shown in figure 1.
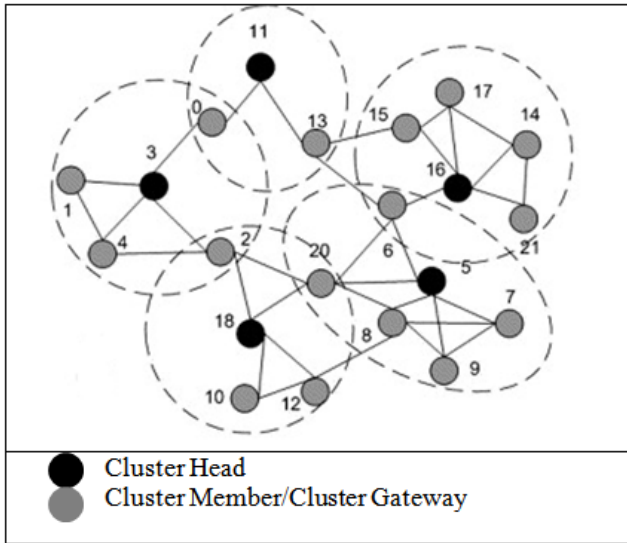
Fig. 1 Example of a clustered structure for a MANET.

We have based our work on the energy model proposed by NS2 [10].Energy consumption of each node is measured using the Eq. 5. The residual energy will be used as a metric to optimize the number of clusters Head and to maximize the network lifetime.

At the beginning of each simulation, the node energy is set to the initial energy which is then decremented when transmitting or receiving packets. The following equations represent the energy used (in watt) by a node i when a packet is transmitted (Eq. 1), received packet (Eq. 2), or on idle state (Eq. 3) during a Δt period of time.

Transmitted Energy: $eitx(Δt) = P\_tx * txtime;$ *(1)*

Receiving Energy: $eirx(Δt) = P\_rcv * rcvtime;$ *(2)*

Idle Energy: $eiidle(Δt) = P\_idle * idletime;$ *(3)*

$eitotal(Δt) = eitx(Δt) + eirx(Δt) + eiidle(Δt);$ *(4)*

$Ei(t) = Ei(t-Δt) − eitotal (Δt)$ *(5)*

Where,

Txtime = Transmitting time for a packet,

Rcvtime = Receiving time for a transmitted packet,

Idletime = Time where a node is in the idle state,

$Ei(t)$ = Residual energy at a given time t,

$Ei(t-Δt)$ = Residual energy total at t-Δt,

$eitotal (Δt)$ = Energy total consumption during the interval [t-Δt, t].

5.1 Energy Consumption Model

Each node's radio can be in one of the following three states:
- **Transmitting:** node is transmitting a message with transmission power *P_tx*.
- **Receiving:** node is receiving a message with reception power *P_rcv*.
- **Idle:** when no message is being transmitted or received, the nodes stay idle and keep listening the medium with *P_idle*.

Since transmission is more expensive than receiving, and nodes in idle state consume less energy, we therefore have the following power condition (Eq. 6):

$$P\_idle < P\_rcv < P\_tx \quad (6)$$

Each state operates at different power levels and these levels are fixed for all nodes in the network.

5.2 Election algorithm of clusters Head

In a clustered OLSR network, each node can be in one of three modes:
- **Undecided:** When a node has just arrived, or it has just left its cluster and has no neighbor in its neighborhood, its status is not decided yet. There is no clusters Head or cluster member. It must wait for the receipt of HELLO messages.
- **Cluster Head**: The node was exchanged HELLO messages, and it has the highest value of residual energy. It creates a cluster in which it was appointed head of the cluster.
- **Member:** The node has exchanged HELLO messages; it residual energy is less comparing to its neighbors nodes, and is part of the cluster members.

Transitions between these modes can be summarized by the following state/transition diagram (Figure 2).
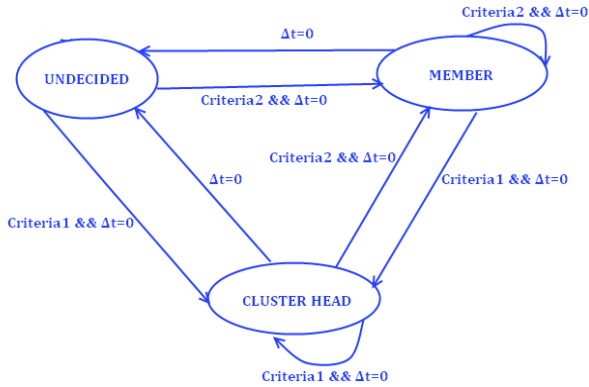
Fig. 2 Transitions between modes. (Criteria1: Ei ≥ E; Criteria2: Ei< E).

Δt: this time represents the clustering interval, at which each node restarts the process of criteria calculation.
Ei is the residual energy of each node and E = Max(Ei).
Undecided node is the startup mode for each node. The mobile unit uses the received HELLO message to calculate periodically its residual energy. Thus each node can detect network conditions favorable to change its mode.

• If criteria 1 (*Ei ≥ E*) is true: the node moves from Undecided to cluster Head mode. Once in this mode, the node *i* initialize a period of time Δt. If after this period, the node *i* has received no HELLO message, that means it has no neighbors in its radio range, so it decides to move to mode Undecided.

• If criteria 2 (*Ei<E*) is true: the node moves from Undecided to Member. Once in the member mode, the node i initializes the timeout Δt. If after passing this time, the node i has received no HELLO message that means it has no neighbors in its radio range, so it decides to move to mode Undecided.

• If the node i is in the Member mode (respectively in mode clusters Head), and it receives a HELLO message with criteria 1 (respectively criteria 2), it moves in clusters Head mode (respectively moves in Member mode) because its mode has to change.

• If the node i is in Member mode (respectively in mode clusters Head), and it receives a HELLO message with criteria 2 (respectively criteria 1), it remains in Member mode (respectively remains in mode clusters Head) because its mode has not changed.

6. Simulations and Results

In this work, we have taken two different scenarios. In the first scenario, the random waypoint mobility model (RWP) [11] is used with different sizes of the network (different network densities) and the speed of nodes varying from 0 to 30 m/s (108 km/h). This scenario is used to show the impact of the network size on the clustering process.

Simulation parameters are detailed in table 1.

Table 1: Parameters for Scenario 1.

Parameter	Values
Number of nodes	10,20,30,40,50,60,70,80, 90 and 100
Maximum Speed	30 m/s
Minimum Speed	0 m/s
Node flows	10
Simulation time	300 s
Packet Size	512
Traffic Type	CBR
Dimension of Space	1000x1000 m
Pause Time	0 m/s
Initial node energy (W)	1000 W
Power Consumption *Pr*	1.0 W
Power Consumption *Pt*	1.4 W
Power Consumption *Pidle*	0.4 W

In the second scenario, the number of nodes was fixed to 50 and we vary the mobility of nodes form 0 to 40m/s (144km/h). This scenario allows us to study the impact of mobility and speed on the clustering process.
Experiments have been conducted on NS-2 [10] with a focus on the clusters Head election algorithm in OLSR to find an optimal number of clusters that will enhance the lifetime and performance of the MANET. The Average Number of Clusters during a simulation is measured; it gives us an idea of the behavior of the clustering process.
Figure 3 (first scenario) compares the average number of clusters formed for OLSR with respect to the number of nodes in the Ad hoc network. It can be seen that when increasing the density (number of mobile nodes on the simulation square), the election algorithm produces less clusters (13 clusters for 80 nodes) than for low density (4 clusters for 10 nodes). This implies that our approach will work better within dense networks.
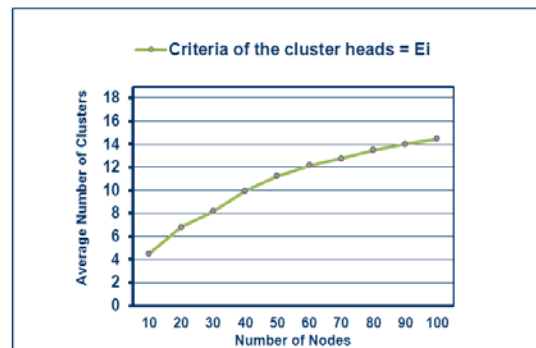

Fig. 3 Average number of clusters vs. number of nodes.

Figure 4 depicts the second scenario; it shows the behavior of the average number of clusters built based on the maximum speed of nodes in the network. The number of nodes in the network was fixed to 50. In a low mobility environment, the figure 4 shows a number of 13 to 18

clusters. When the speed varies from 10 to 40 m/s, the number of formed clusters seems to be constant around 11 clusters.
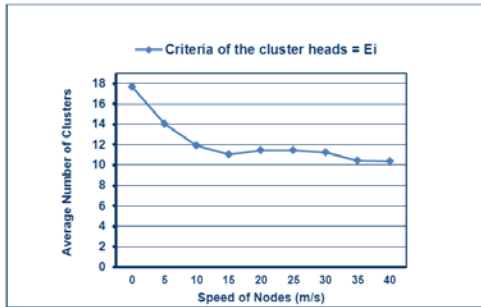

Fig. 4 Average number of clusters vs. speed of nodes.

Widely varying speed of nodes is expected to have a significant impact on the number of clusters of the routing protocol OLSR and automatically a reduced number of clusters Head having a high density of nodes.

7. Clustering and Mobility models

It is important to use a mobility model that can emulate the motion close to real life applications. The performance of routing protocol greatly depends on the mobility pattern used on the network.

To evaluate the performance of our clustering algorithm for different mobility models, we have performed some simulations for the following mobility models: Random waypoint (RWP) [11], Random Direction (RD) [12] models and Reference Point Group Mobility (RPGM) [13].

In Random Waypoint mobility model (RWP), parameters to be specified are: pause time, minimum speed and maximum speed. Each mobile node starts from a randomly chosen position and stays immobile for the pause time duration. When the pause time expires, a destination and moving speed are randomly picked. The speed is uniformly chosen between the specified maximum and minimum. Once the mobile reaches the destination, the process of pausing, choosing destination and speed will start again. This model can, for example, emulate the rescue operations in a disaster area.

In Random Direction model (RD), a mobile node randomly selects a movement degree to travel in a particular direction until it reaches the destination boundary area with a given speed. On reaching, it stops for a given pause time before selecting a new direction to move. This model can be used when exploring some unknown areas.

In Reference Point Group Mobility (RPGM): mobile nodes are divided into groups at the beginning of the simulation. Each group has a central point. The motion of this central node defines the group motion. Each individual node will have one reference point when moving. The motion of each node is determined by two vectors: group motion vector and individual motion vector with respect to its reference point. The net motion vector of each node can be seen as the sum of the two vectors. The group motion is defined by specifying some check points. Central nodes must follow and pass these check points. This model is more realistic and can be used to simulate tactical military operations or tourists tourney.

To observe the behavior of our algorithm relating to these mobility models, we have redone the same simulations (scenarios 1 and 2) for the tree mobility models, and we have obtained the following results.

Fig. 5 Average number of clusters vs. number of nodes for speed 30 m/s (scenario 1).

Figure 5 shows the average number of clusters formed along the simulation in terms of number of nodes in the network. We note that, when increasing the density, our clustering solution gives better results (a reduced number of clusters) with the RPGM model. The combination of groups and clusters looks like a network having three levels of hierarchy. The existence of groups with central nodes helps more in building clusters. A cluster can contain one or more groups.
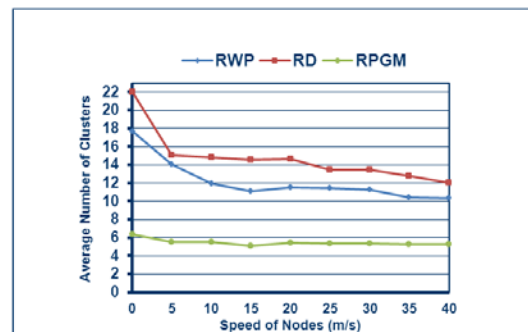

Fig. 6 Average number of clusters vs. speed of nodes (scenario 2).

Figure 6 shows the average number of clusters formed along simulations when varying the speed of nodes. We note that, when increasing the mobility, our clustering solution gives better results (a reduced and stable number of clusters) with the RPGM model and becomes independent of nodes' speed. The concept of group gives more stability when forming clusters on the network. The RPGM provides a high speed and spatial correlation between nodes, which leads to high link durations and less change in the relative network topology.

Figure.7 shows the energy consumption for the three tested mobility models. It can be seen that RPGM model consumes less energy than the other models. In a group moving RPGM environment, the network is more stable and less route changes are operated. This fact implies a significant reduction in power consumption that is needed for maintaining route information. This ensures a long lifetime for the MANET.
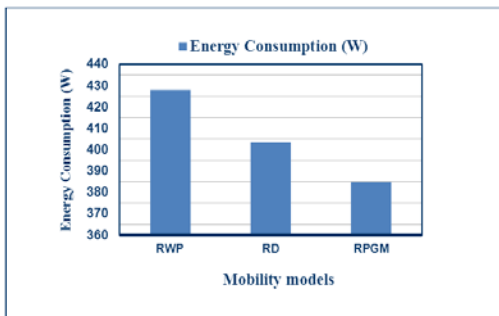

Fig. 7 Energy consumption vs. Mobility Models.

8. Performance Evaluation and Comparison

In this section, we present some conducted simulations to compare the Average number of clusters of the original OLSR protocol based on the residual energy (Ei), with some related approaches based on the density parameter: Density at one hop based clustering ($Di1$) [8], and Density at two hops or MPR based clustering ($DMPRi$) [9].
We have taken the same previous two scenarios: one varying the number of nodes (density of the network) and the second varying the speed of nodes (mobility of the network).
Figure.8 shows the number of clusters formed in terms of number of nodes in the network. We note that our clustering solution Ei gives the best results. This can be explained by the fact that our selected clusters Head have more residual energy and can live more than in the other approaches. Where the cluster Head rapidly dies, this can causes the re-election of new clusters Head. In D1i and $DMPRi$, a MPR can be elected as cluster Head and it's known that MPRs consume more energy than normal

nodes. This can lead to some problems of performance and links failure.
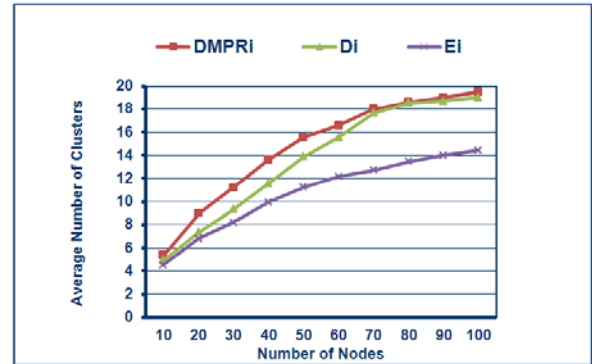

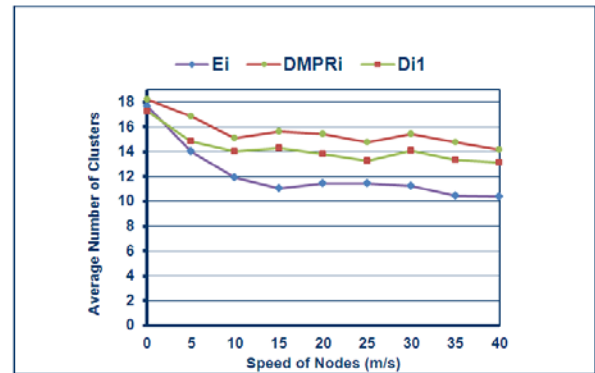Fig. 8 Average number of clusters vs. number of nodes for speed 30 m/s.

Fig. 9 Average number of clusters vs. speed of nodes.

Figure 9 shows the average number of cluster for the three clustering algorithms: $Di1$, $DMPRi$ and our clustering algorithm Ei when the speed of nodes varies. The three algorithms have shown a stable number of clusters when the speed varies between 10 and 40 m/s. It can easily be observed that residual energy Ei performs much better than $Di1$ and $DMPRi$ for moderate speeds(speed between 10 m/s to 40 m/s) because it will generally use normal nodes (not MPR nodes) as clusters Head. MPR nodes consume much energy to forward control messages (Hello and TC) and will never be elected as clusters Head in our proposed algorithm.

9. Conclusion

We have proposed a novel energy-aware based on clustering approach that we have adapted to be implemented in standard OLSR. The solution we propose in this work enables clustering for OLSR networks without causing any change in the structure of control messages.

Our alternative divides the network into disjoint clusters. It behaves like standard OLSR in intra-cluster and involves only nodes which form the connected dominating set in inter-cluster. Thus, it significantly reduces the amount of control traffic.

To evaluate our proposal, we have measured the behavior of our clustering algorithm using several mobility models. According to the obtained results, we notice an improvement with the adopted solution comparing to others based on the density criterion. The obtained results show that the RPGM model behaves well, produces a reasonable number of clusters and consumes less energy within the network.

This work can be continued in many directions, we will try first to combine the energy with other criteria (density and mobility) to produce more efficient clustering. We aim also to study the impact of differentiated traffic (essentially two QoS classes: real time and best effort) on our clustering algorithms. Overlapped clustering (one cluster per QoS class) will be experimented.

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