Clustering for Indoor and Dense MANETs

Luís Conceição and Marilia Curado

Dept. Informatics Engineering, Centre for Informatics and Systems,
University of Coimbra
{lamc,marilia}@dei.uc.pt

Abstract. Clustering is the most widely used performance solution for Mobile Ad Hoc Networks (MANETs), enabling their scalability for a large number of mobile nodes. The design of clustering schemes is quite complex, due to the highly dynamic topology of such networks. A numerous variety of clustering schemes have been proposed in the literature, focusing different characteristics and objectives. In this work, a new clustering scheme, designed for large cooperative environments, is proposed, namely Clustering for Indoor and Dense MANETs (CIDNET). CIDNET was evaluated featuring its stability, amount of clustered nodes and network load. Results demonstrate high and constant levels of network stability.

Keywords: MANET, distributed clustering, cooperative work, stability, indoor environment

1 Introduction

MANETs are autonomous systems, capable of self deployment and maintenance, not requiring infrastructure support for their operation. As a result, the topology of such networks is very dynamic, especially due to the unpredictable behaviour of the nodes involved. In this context, numerous clustering schemes were developed, following different approaches and objectives, such as stability, low maintenance overhead or energy efficiency. Each one attempts to obtain the best efficiency by varying the characteristics of the system, like the usage of clusterheads and gateways, the maximum hop distance between nodes and the location awareness. However, there are very few clustering schemes which provide a fully distributed cluster structure with no clusterheads.

In recent years, a wide growth of wireless systems has been noticed. Wireless technologies are present in consumer applications, medical, industrial, public services, transports and much more. Therefore, there is a high demand for accurate positioning in wireless networks, either for indoor or outdoor environments. Concerning the nature of the application, different types of location are needed, which can be characterized as physical location, symbolic location, absolute location and relative location.

Currently, there are many wireless location technologies, such as Radio Frequency (RF) based (WLAN, Bluetooth, ZigBee, RFID), Infrared (IR), Ultrasound, and Global Positioning System (GPS). However, each technology has its advantages and disadvantages, and environment scope. No single technology is applicable to all services and circumstances. Recent studies have focused on developing indoor location systems, since GPS offers a good solution but for outdoor environments.

There are many solutions using location awareness designed to improve a wide diversity of goals, e.g. [1] and [2]. However, to the best of our knowledge, none focusing only the improvement of clustering in MANETs has been proposed. In this work, a new clustering scheme is proposed, named as Clustering for Indoor and Dense MANETs (CIDNET), aiming to improve the stability of the cluster structure. CIDNET takes advantage of node location information in order to provide a more efficient cluster creation and management, ultimately leading to a stabler network. The remaining of this document is organized as follows. Section 2 discusses the related work, covering some of most significant clustering schemes and location sensing solutions. Section 3 describes the CIDNET clustering scheme. Section 4 performs the evaluation of CIDNET and, finally, Section 5 concludes the article.

2 Related Work

Currently, there is a wide range of clustering and location algorithms, aiming at different objectives and scopes. This section exploits provides an overall description of the most popular algorithms in both areas, identifying their main characteristics and technologies.

2.1 Clustering

Clustering algorithms can be classified according to different characteristics and objectives [3]. One of the common features in clustering schemes is the utilization of clusterheads (CH) and most of the proposed schemes rely on centralized nodes to manage the clusters structure. The utilization of gateway (GW) nodes is also another important characteristic that is present in the majority of clustering schemes. Other properties of clustering schemes concern the single-hop or multi-hop environments, the multi-homing (MH) support, embedded routing capabilities and location awareness.

Combining the possible characteristics, each proposed clustering scheme attempts to accomplish a specific objective. The Stable Clustering Algorithm (SCA) [4] aims at supporting large MANETs containing nodes moving at high speeds by reducing re-clustering operations and stabilizing the network. To meet these requirements, the algorithm is based on the quick adaptation to the changes of the network topology and reduction of clusterhead reelections. A weight-based clustering scheme, named Distributed Weighted Clustering Algorithm (DWCA), was proposed with the objective to extend the lifetime of the network, by creating a distributed clustering structure [5]. The election of clusterheads is based on the weight value of nodes, which is calculated according to their number of neighbors, speed and energy. The Enhanced Performance Clustering Algorithm

(EPCA) [6] is also a weight based clustering solution. Once more, the weight parameters are only taken into account for the selection of the clusterhead. The Trust-related and Energy-concerned Distributed MANET Clustering (TEDMC) [7] is also a scheme driven by energy concerns. TEDMC considers that the most important nodes are the clusterheads, and therefore it elects them according to their trust level and residual energy. There are also clustering schemes capable of performing route discovery, such as the On-Demand Clustering Routing Protocol (OCRP) and On-Demand Routing-based Clustering (ORC) [8, 9]. These schemes are capable of building cluster structures and routing paths on-demand. In these schemes, only the nodes that are necessary to satisfy a routing path are bounded to the cluster structure. The On-Demand Group Mobility-Based Clustering with Guest Node [10] provides a solution with the main purpose of building a cluster structure capable of supporting several types of routing protocols with identical efficiency. SALSA [11] is also a fully distributed scheme, aiming to provide stability at a reduced maintenance overhead. It utilizes two new mechanisms to accomplish its goal, the clustering balancing mechanism and a best clustering metric, which evaluates the most suitable cluster to join based on its connectivity.

2.2 Location Sensing Systems

In recent years, a wide growth of wireless systems has been noticed. Wireless technologies are present in consumer applications, medical, industrial, public services, transports and much more. Therefore, there is a high demand for accurate positioning in wireless networks, either for indoor or outdoor environments. Concerning the nature of the application, different types of location are needed, which can be characterized as physical location, symbolic location, absolute location and relative location. Physical location is expressed in coordinates, identifying a point on a map. Symbolic location refers to a location in natural language, such as a coffee shop, office, etc. Absolute location uses a global shared database system, which references all located objects. Finally, relative location is usually based on the proximity of devices, e.g. known reference points, providing an environment-dependent location. The latest is the most common used paradigm.

The main challenge of location estimation relies on the radio propagation interferences, due to severe multipath, low probability of a Line of Sight (LOS) path, reflecting surfaces, and environment dynamic characteristics, such as building restructuring and moving objects. There are three main techniques to model radio propagation: trilateration, fingerprinting and proximity.

- **Trilateration** - The process consists on determining radial distance, obtained by the received signal, from three or more different points. It can be used on most RF based technologies by measuring radio propagation characteristics, thus calculating distances from two different points.
- **Fingerprinting** - Algorithms first collect features (fingerprints) of a scene and then estimate the location of devices, by matching (or partially match-

ing) real time (online) measurements with fingerprints. Most of these algorithms define location fingerprints based on Received Signal Strength (RSS) values, previously obtained (offline). Thus, the fingerprinting technique must occur in two stages: the offline gathering of fingerprints, where multiple measurements of known locations are stored in a database, and a online location estimation, which obtains the most suitable match from the database. The major challenge of this technique is the dynamic environments, since building layouts and arranjement of objects are likely to change, thus affecting RSS measurements.

- **Proximity** - Algorithms determine symbolic locations. Typically, it relies on the installed base stations, each classified to be in a known position. When a mobile device is detected by the Base Station (BS) antenna, it is considered to be located in its coverage radius. Moreover, when multiple antennas detect a device (overlapping), is is considered to be located in the BS with the strongest signal, whereas the RSS value is typically used.

There are many proposed wireless location solutions, using different technologies, scopes and with different accuracies. The Active Badge [12] system was a pioneer contribution in location sensing systems and source of inspiration to many following projects. The main goal of this solution is the ability to locate persons or objects inside public buildings like hospitals. Each person wears a badge, which emits an IR signal within every 10 seconds. The sensors placed at known positions are responsible to receive the unique identifiers and relay these to the location manager software. Emitted signals are reflected by surrounding materials and therefore are not directional when used inside small rooms. Bahl *et al.* [13] proposed an WLAN indoor location tracking system called RADAR. In this work, two main types of approaches are employed to determine user location: empirical model and radio propagation model. The first depends on a database that consists of previously measured signal strength of points, recording user orientation and signal strength for each BS. In the second approach, authors adopted the Floor Attenuation Factor (FAF) and Wall Attenuation Factor (WAF) models [14], taking into consideration the number of obstructions walls and material types between the user and the BS. Raghavan *et al.* [15] proposed an location system, for indoor environments, suitable to any technology that provides Receiver Signal Strength Indication (RSSI) values, such as Bluetooth and WLAN. However, since it is designed to locate robots, the authors chose to use Bluetooth, as power consumption is significantly lower than WLAN, despite of providing a higher data rate. The method can provide more accurate results, however at a higher processing cost, by discarding the points with a low error, and repeating the computation process to the remaining. LANDMARC [16] is an indoor location sensing system using active Radio Frequency Identification (RFID), aiming to locate objects. The infrastructure consists of RFID readers, active RFID tags and a management server. All objects must be tagged with an active tag. Active tags are also deployed across the scenario, acting as reference tags, aiding the location process with a low installation cost. The main disadvantage of this approach resides in the sequential scan of all reading ranges, which takes about one minute per cycle. Cheng [17] proposed a room-based location technology using ZigBee wireless technology. Two ZigBee nodes are placed inside each room, one at the door, with the antenna pointing inwards the room and adjusted within 1.5 meters, and a second in a unspecific wall, adjusted within 10 meters. When the user tag passes the door or room and the secondary node senses the user tag, it can be certain that the user is in that specific room. The Bat system [18] present an location approach based on ultrasound. Each person or object carries a device called Bat that periodically sends an ultrasonic signal. Receivers are placed to fixed positions at the ceiling of rooms, and connected to a wireless network. Analyzing the arriving times, provided by several receiving units, the core management system calculates the position of devices. This project shows that ultrasound provides an high precision location sensing, however ultrasound is highly vulnerable to interferences. Moreover, the installation cost of this system can be very high, which difficult the extension of the system for large areas. Cricket [19] is another ultrasound based location system. In contrast with the Bat system, mobile devices are responsible to determine the location by themselves, ensuring privacy to users. Also, instead of receivers, beacons are placed in the ceiling, which periodically send radio and ultrasonic signals. Using multiple signals from different beacons, the mobile device calculates the current position.

3 Clustering for Indoor and Dense MANETs (CIDNET)

There is a large variety of clustering schemes in literature, with different mechanisms and objectives, aiming to build a suitable hierarchical structure in order to provide an efficient routing in MANETs. Despite the goal of the majority of schemes, which aims at the impromptu deployment of wireless networks in remote environments, clustering can also be an asset in common scenarios, where network infrastructures are present. Typical WLAN network infrastructures do not efficiently support a large quantity of associated nodes, becoming overloaded and consequently unresponsive. The utilization of ad-hoc networks in this environments would be a solution to address this issue.

CIDNET is a fully distributed clustering scheme designed for dense cooperative environments, where existent network infrastructures are not sufficient. This proposal offers a clustering solution for ad-hoc networks, utilizing surrounding network infrastructure as context information to ease cluster management. CIDNET uses the existent Access Points (APs) as a proximity location reference, in order to facilitate cluster creation and management. As studied in the previous section, location sensing systems are complex, particularly when concerning trilateration and fingerprinting. Thus, CIDNET is based on proximity location, relying on APs to determine the location information for the entire network. Nodes scan for WLAN Service Set Identifier (SSID) broadcasts and create clusters according to that information. This mechanism is more efficient since all nodes in-range to an AP are instantly assigned to a cluster (according to the SSID string) and an initial waiting period for cluster creation is not necessary. Furthermore, the proposal implements some mechanisms of the SALSA algorithm, namely the automatic clustering balancing and most suitable joining cluster determination.

3.1 Location Sensing and Dissemination

In CIDNET there are two distinct types of nodes. The nodes that are in-range with at least one AP, named as anchor nodes, and the nodes that are distant and not capable of receiving SSID broadcasts, named as blind nodes.

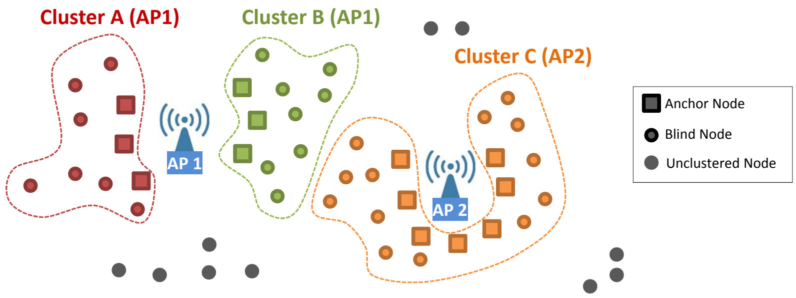


Fig. 1: CIDNET Clustering Example

Anchor nodes have the additional responsibility of creating clusters, based on the nearby SSID, and inform its blind neighbours that there is an AP nearby. Upon receiving this information, blind nodes decide whether to join the cluster associated with that AP and continue to broadcast the received information to its neighbours, until a configurable TTL reaches 0. Figure 1 shows a possible clustering scenario of CIDNET. As depicted, only anchor nodes (represented as a square dots) have connectivity to APs. Blind nodes (round dots) receive broadcast of the APs and join the clusters. To be noted that multiple clusters can be associated to the same AP, like Cluster A and Cluster B. In the best case scenario, each broadcast would be associated with one single cluster, however this situation is not always possible. Looking at Figure 1, Cluster A and B are associated with one specific SSID AP broadcast and they cannot be merged into one single cluster, since their nodes do not have connectivity. Addicionally, there are nodes that remain completely isolated and cannot be associated to the cluster structure. This situation occurs when nodes do not have any connectivity, even through neighbour nodes, to APs or AP broadcast messages did not reach them due to TTL expiry.

3.2 Node States

Nodes can be in one of three distinct states, namely *Unclustered*, *Clustered* and *Clustered-GW*.The *Unclustered* state typically represents a temporary role, as the node is waiting to be assigned to a cluster. In this state, when the node discover at least one APs it becomes an anchor node and creates a cluster. On the other hand, if the node receives an AP broadcast, it assumes the blind node role and decides, based on the received broadcasts, what is the best cluster to join. Nodes in the *Clustered* state usually represent the majority of nodes on the network, either anchor or blind nodes, whereas all in-range nodes must belong to its cluster. Thus, the communication with foreign nodes (i.e. nodes assigned to a different cluster) is performed through gateway nodes. Finally, the *Clustered-GW* state is assigned to nodes that have in-range foreign nodes, i.e. they must have direct connectivity with at least one different cluster. Thus, they are responsible of forwarding inter-cluster maintenance messages and typically are located on the edge of clusters.

State Transitions. The *Unclustered* state occurs on two different situations:

1. Node isolation (geographic position) - in this case the node does not have any in-range neighbour nodes or AP's, therefore cannot create or be assigned to a cluster
2. Node isolation (TTL expiry) - in this case, nodes have connectivity to neighbour nodes that may be clustered, however due to the TTL expiry of AP broadcasts, they cannot be associated with a cluster. This mechanism is necessary as it prevents the creation of very large clusters, leading to a higher instability of the network

Unclustered to Clustered This state occurs when a node becomes aware of an AP broadcast or it has direct connectivity with an AP. In the first situation, the node has to evaluate which is the best cluster to join (if received distinct and multiple AP broadcasts) based on the number of received broadcasts per AP. This is, the more received broadcasts announcing an AP, the more neighbour nodes associated with that same AP, leading to a better connection and ultimately to a better stability. In the second situation, upon detecting an AP, nodes automatically create a cluster and broadcast a message announcing its neighbours the presence of an AP.

Unclustered to Clustered-GW This transition is very similar to the previous, but with one difference. When a node becomes clustered, it is considered a gateway if it has direct connectivity with neighbour nodes belonging to different clusters.

Clustered to Clustered-GW This transition occurs when a node becomes aware of clusters, excluding its own.

Clustered-GW to Clustered Whenever a clustered gateway node loses connection with all its foreign clusters, it automatically transits to a normal clustered state.

Clustered/Clustered-GW to Unclustered A node becomes unclustered when willingly disconnects from the network or loses connection with all its neighbor nodes. When this situation occurs, it is necessary to verify the consistency of the cluster, i.e. guarantee that all home nodes can communicate with each other.

4 Simulation Evaluation

To examine the effectiveness of CIDNET, a simulation was performed using the OPNET Modeler [20]. Therefore, the main purpose of this simulation evaluation is to assess the stability and low overhead capabilities of the proposal. To accomplish this objective, a set of different simulation environments, featuring the network size and speed of nodes, were defined.

4.1 Environment and Parameters

The scenarios utilized to evaluate CIDNET were selected in such a way that they represent, as much as possible, realistic scenarios. In this specification the evaluation parameters can be divided in two groups, the fixed-value and variable-value parameters, according to whether their value changes for different simulation scenarios (Table 1).

Table 1: Simulation parameters

Fixed-value parameters	
Simulator	OPNET Modeler 16.0
Field Size (m^2)	500 × 500
Node mobility algorithm	Random Waypoint Model
Pause time (s)	50
Transmission range (m)	150
WLAN IEEE Standard	802.11b (11 Mbps)
Simulation time (s)	900
Number of APs	49
AP Broadcast TTL	5
Variable-value parameters	
Network size (number of nodes)	80; 160; 240; 320; 400
Node maximum speed (m/s)	0; 1; 2

CIDNET relies on APs to the creation and position of clusters. Since APs will determine the position of clusters, it would be desirable to evenly scatter them across the deployment scenario. Thus, to a first validation of CIDNET, all scenarios will contain 49 APs (7 × 7), placed in a grid fashion. The parameters that most influence the scalability of the network are the network size (number of nodes) and the maximum speed that nodes can achieve. This simulation study aims to evaluate areas with the existence of network infrastructures, e.g. an university campus. Thus, a random model for mobility, namely the Random Waypoint, was chosen to simulate the movement of people. Also, the average speed on foot of humans does not exceed 2 m/s, which was considered as a good maximum movement speed. Each simulation execution was repeated 30 times, assigning to each a distinct seed value.

4.2 Results

This section presents the obtained results from the CIDNET simulation. As previously mentioned, CIDNET is a completely new algorithm, implementing some features of the SALSA scheme. For that reason and since both CIDNET and SALSA are full distributed algorithms (i.e. do not use clusterheads), the discussion of the following results will be conducted according to the results obtained in SALSA.

Number of Clustered Nodes. This metric provides the number of nodes that are associated with the cluster structure.

Table 2: Amount of clustered nodes (in percentage)

(a) CIDNET

Network Size \ Speed (m/s)	**0**	**1**	**2**
80	90.54	86.10	85.51
160	91.68	87.56	86.89
240	92.98	88.97	87.59
320	94.51	90.30	88.90
400	96.10	93.31	92.01

(b) SALSA

Network Size \ Speed (m/s)	**0**	**1**	**2**
80	88.91	90.54	90.69
160	91.21	92.88	91.54
240	93.28	92.95	90.89
320	94.55	92.10	89.28
400	95.29	91.50	87.21

Table 2a shows the percentage of clustered nodes for the different network sizes and node speeds in CIDNET. The percentage of clustered nodes for large networks is slightly higher than for smaller networks. This occurrence is due to the node density increase, i.e. the probability of a node being communication in-range with another is greater for networks with more nodes. In SALSA (Table 2b) the percentage of clustered nodes generally increases for larger networks, with the exception of scenario of nodes moving at the maximum speed of 2 m/s and larger than 240 nodes. This fact occurs due to the high density of nodes in the network and shows that SALSA is becoming overloaded, thus not being able to cluster such a large quantity of nodes.

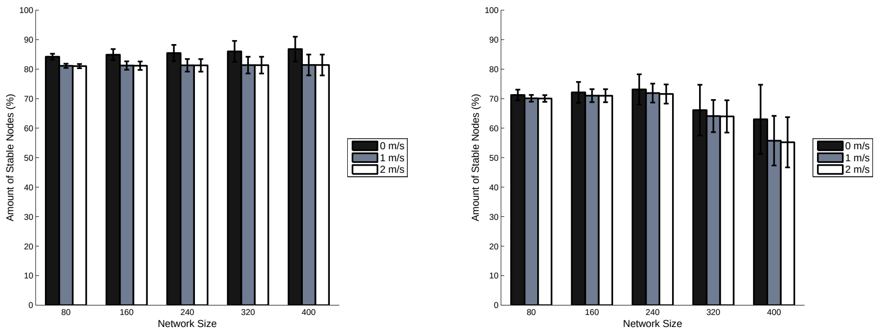
Cluster Stability The stability of clusters can be measured according to the amount of time that nodes belong to a cluster, without suffering re-clustering operations.

For this analysis, a cluster stability metric is utilized, which defines a stability time (ST), from which nodes are considered to be stable (1).

$$ST = k \times \frac{r \times p}{v \times d} \tag{1}$$

where r is the transmission range of nodes, p is the pause time, v the average of node speed (mean value of minimum and maximum speed), d the density of nodes (number of nodes per Km^2) and finally, k represents an arbitrary constant, equal in all simulation executions, enabling the transformation of the ratio to a real execution time.

The stability metric ST provides a mechanism of determining the amount of nodes that were stable during the simulation for a period greater than the ST



(a) CIDNET (b) SALSA

Fig. 2: Amount of stable nodes (in percentage)

value. Figures 2a and 2b show the number of stable nodes per network size and their percentage, at different node speeds.

As a quick first analysis of the Figures, CIDNET clearly outperforms SALSA in terms of stability. CIDNET presents higher stability levels for all scenarios. Furthermore, the percentage of stable nodes is almost constant for all network sizes, whereas SALSA shows a significant decline for network sizes greater than 240 nodes. As previously seen, the amount of clustered nodes in SALSA also decreased at node speed of 2 m/s for network sizes greater than 240 nodes. Once again, this fact occurs due to the high density of the network, leading to instability. CIDNET however, is capable of overcoming this issue, as it always forces clusters to be near APs, providing a stabler network. There is, however some small drawbacks. In CIDNET the number of clustered nodes for dynamic nodes (1 m/s and 2 m/s) is slightly lower in smaller networks, as it can be seen in Table 2.

Network Load The network load represents the received and transmitted traffic in the network. This metric translates the overall weight of the network, including the clustering control overhead.

Table 3: Average Network Load (Kbit/s)

(a) CIDNET

Speed (m/s) / Network Size	**0**	**1**	**2**
80	47,11	47,89	48,08
160	56,56	57,34	57,53
240	68,54	69,32	69,51
320	78,00	78,78	78,97
400	87,12	87,90	88,09

(b) SALSA

Speed (m/s) / Network Size	**0**	**1**	**2**
80	10,30	13,25	14,21
160	12,98	14,21	15,74
240	21,59	24,12	24,54
320	36,87	38,13	38,90
400	47,12	48,50	49,12

Table 3a and Table 3b show the average network load, for different velocities and network sizes, for CIDNET and SALSA, respectively. CIDNET handles clustering with a significant higher overhead. This is mainly due to the broadcasts announcing the presence of Access Points (APs). As previously described, anchor nodes broadcast messages announcing the presence of APs, and consequently, blind nodes follow the broadcasts until a configurable TTL expires. Naturally, if the TTL value is lower, CIDNET will present lower overhead levels. On the other hand, this value cannot be too small, otherwise there would be many unclustered nodes. Despite presenting a significant higher overhead, CIDNET can outperform SALSA in the amount of clustered nodes and, most importantly, in stability.

5 Conclusion

This article proposed CIDNET, a new clustering scheme aiming to improve the stability of the network, in order to provide reliable and large cooperative environments. This clustering scheme employs a context aware paradigm, utilizing the existent network infrastructure as a location reference to improve the stability and management of the cluster structure. Evaluation results shown that CIDNET outperforms SALSA in both the amount of clustered nodes and stability, despite of using a higher management overhead. Nevertheless, CIDNET never overcomes an average of 90 kbits/s in the entire network, which is pretty reasonable.

Acknowledgments

This work was supported by FCT project MORFEU (PTDC / EEA-CRO / 108348 / 2008). The authors would like to thank the OPNET University Program for the licenses provided for the OPNET ModelerWireless Suite R.

References

1. J.-I. Kim, J.-Y. Song, and Y. cheol Hwang, “Location-based routing algorithm using clustering in the manet,” in *Future Generation Communication and Networking (FGCN 2007)*, vol. 2, dec. 2007, pp. 527 –531.
2. T. Wang and Z. Yang, “A location-aware-based data clustering algorithm in wireless sensor networks,” in *Communication Systems, 2008. ICCS 2008. 11th IEEE Singapore International Conference on*, nov. 2008, pp. 1 –5.
3. J. Yu and P. Chong, “A survey of clustering schemes for mobile ad hoc networks,” *Communications Surveys & Tutorials, IEEE*, vol. 7, no. 1, pp. 32–48, Qtr. 2005.
4. F. Tolba, D. Magoni, and P. Lorenz, “A stable clustering algorithm for highly mobile ad hoc networks,” *Systems and Networks Communications, 2007. ICSNC 2007. Second International Conference on*, pp. 11–11, Aug. 2007.
5. W. Choi and M. Woo, “A distributed weighted clustering algorithm for mobile ad hoc networks,” *Telecommunications, 2006. AICT-ICIW ’06. International Conference on Internet and Web Applications and Services/Advanced International Conference on*, pp. 73–73, Feb. 2006.

6. R. Zoican, “An enhanced performance clustering algorithm for manet,” in *MELECON 2010 - 2010 15th IEEE Mediterranean Electrotechnical Conference*, april 2010, pp. 1269 –1272.
7. Z. Qiang, Z. Ying, and G. Zheng-hu, “A trust-related and energy-concerned distributed manet clustering design,” in *Intelligent System and Knowledge Engineering, 2008. ISKE 2008. 3rd International Conference on*, vol. 1, nov. 2008, pp. 146 –151.
8. C. Huang, Y. Zhang, X. Jia, W. Shi, Y. Cheng, and H. Zhou, “An on-demand clustering mechanism for hierarchical routing protocol in ad hoc networks,” *Wireless Communications, Networking and Mobile Computing, 2006. WiCOM 2006.International Conference on*, pp. 1–6, Sept. 2006.
9. C.-H. Hsu and K.-T. Feng, “On-demand routing-based clustering protocol for mobile ad hoc networks,” *Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on*, pp. 1–5, Sept. 2007.
10. A. Dana, A. Yadegari, A. Salahi, S. Faramehr, and H. Khosravi, “A new scheme for on-demand group mobility clustering in mobile ad hoc networks,” *Advanced Communication Technology, 2008. ICACT 2008. 10th International Conference on*, vol. 2, pp. 1370–1375, Feb. 2008.
11. L. Conceição and M. Curado, in *Ad-hoc, Mobile, and Wireless Networks*, H. Frey, X. Li, and S. Ruehrup, Eds.
12. R. Want, A. Hopper, V. Falcão, and J. Gibbons, “The active badge location system,” *ACM Trans. Inf. Syst.*, vol. 10, pp. 91–102, January 1992. [Online]. Available: http://doi.acm.org/10.1145/128756.128759
13. P. Bahl and V. Padmanabhan, “Radar: an in-building rf-based user location and tracking system,” in *INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, vol. 2, 2000, pp. 775 –784 vol.2.
14. S. Seidel and T. Rappaport, “914 mhz path loss prediction models for indoor wireless communications in multifloored buildings,” *Antennas and Propagation, IEEE Transactions on*, vol. 40, no. 2, pp. 207 –217, feb 1992.
15. A. Raghavan, H. Ananthapadmanaban, M. Sivamurugan, and B. Ravindran, “Accurate mobile robot localization in indoor environments using bluetooth,” in *Robotics and Automation (ICRA), 2010 IEEE International Conference on*, may 2010, pp. 4391 –4396.
16. L. Ni, Y. Liu, Y. C. Lau, and A. Patil, “Landmarc: indoor location sensing using active rfid,” in *Pervasive Computing and Communications, 2003. (PerCom 2003). Proceedings of the First IEEE International Conference on*, march 2003, pp. 407 – 415.
17. Y.-M. Cheng, “Using zigbee and room-based location technology to constructing an indoor location-based service platform,” in *Intelligent Information Hiding and Multimedia Signal Processing, 2009. IIH-MSP ’09. Fifth International Conference on*, sept. 2009, pp. 803 –806.
18. A. Harter, A. Hopper, P. Steggles, A. Ward, and P. Webster, “The anatomy of a context-aware application,” *Wirel. Netw.*, vol. 8, pp. 187–197, March 2002. [Online]. Available: http://dx.doi.org/10.1023/A:1013767926256
19. A. Smith, H. Balakrishnan, M. Goraczko, and N. Priyantha, “Tracking moving devices with the cricket location system,” in *In Proceedings of the 2nd ACM International Conference on Mobile Systems, Applications, and Services (MobiSysï¿½04*. ACM Press, 2004, pp. 190–202.
20. OPNET, “Opnet simulator,” 1986, http://www.opnet.com/. [Online]. Available: http://www.opnet.com/