The Dynamic Counting Broadcast in Vehicular Networks

Sarah Omar Al-Humoud
College of Computer Sciences and Information, Imam University, Riyadh, Saudi Arabia
Email: s.alhumoud@ccis.imamu.edu.sa

Lewis M. Mackenzie
Department of Computing Science, University of Glasgow, Glasgow, Scotland
Email: Lewis.Mackenzie@glasgow.ac.uk

***Abstract*—An interesting application of wireless MANETs that is emerging with a high potential for research and development is the inter-vehicle communication where nodes collect and distribute traffic information while moving in urban areas. Broadcasting is a key component to vehicular communication with the aim of high coverage and low medium consumption. Existing broadcasting schemes, however, result in redundancy and medium contention. In this paper a broadcasting scheme with intelligent neighbourhood sensing is produced and tested in two Vehicle Ad Hoc Network (VANET) contexts. Simulation results show that our scheme reduces the amount of unneeded transmissions through the medium even under high density with high traffic loads while maintaining comparable network coverage.**

***Index Terms*—VANET, Broadcast, ns-2, flooding**

I. Introduction

Vehicular Ad hoc NET works (VANETs) emerged from ideas explored in initiatives such as the Intelligent Vehicle/ Highway Systems (IVHS) [1] and is a vital part of what is referred to nowadays as the Intelligent Transportation System (ITS) [2] with initiatives from Japan [3], America [4] and Europe [5]. VANETs are a special kind of MANETs primarily deployed with ideas of transport efficiency and traffic safety in mind [2].

VANET wireless connectivity patterns include: vehicle-to-vehicle (ad hoc), vehicle to infrastructure (cellular network and WLAN) and among vehicles (hybrid) [2]. The distinctive characteristic of VANETs is the highly changeable topology with no central coordination, where network nodes move at potentially high speeds in constrained paths within a built-up area potentially resulting in frequent network partitions leading to immense connectivity issues [2, 6]. With the aim to standardise wireless access in vehicular environments, IEEE amended a specification extension (IEEE 802.11p) to the IEEE 802.11 standard for wireless local area networks (WLANs) providing wireless communications while in a vehicular environment [7]. The IEEE 802.11p standard, also called Wireless Access for Vehicle Environment (WAVE), focuses on possible enhancements to the IEEE 802.11 standard, enabling wireless short-range communications for ITS. The IEEE 802.11p amendment released Physical PHY and MAC layer specifications enabling the VANETs communications in the 5.9 GHz spectrum [8].

Manuscript received October 5, 2012; revised January 2, 2012; accepted Marc 19, 2013

II. Broadcasting

It is important to employ a VANET communication mechanism that addresses its main characteristics satisfying mentioned topological challenges. VANET wireless communication is carried out conventionally by broadcasting or flooding. Broadcasting is a basic communication element used for discovering neighbours, collecting global information, naming, addressing; and route discovery and maintenance for many routing protocols [9]. Broadcasting guarantees coverage but at the penalty of medium saturation caused by redundant transmissions.

In an effort to minimize the disruptive effect of broadcasting researchers proposed several models in the MANET context. Those are stochastic and deterministic. In deterministic schemes, a transmitting node predetermines its forwarding nodes before the broadcast. However, this incurs a large overhead in terms of time and message complexity for building and maintaining a fixed backbone. Deterministic schemes should be avoided in VANET context as high mobility incurs massive topological changes that are expensive to maintain [10].

Stochastic schemes, in contrast, rebuild a backbone from scratch during each broadcast [11, 12]. Nodes make instantaneous local decisions about whether to broadcast a message or not using information derived only from overheard broadcast messages. Consequently, these schemes incur a smaller overhead and demonstrate superior adjustment within changing environments when compared to deterministic schemes [13] this aids in higher scalability which is an important property to

doi:10.4304/jcp.8.12.3298-3304

VANETs spanning large areas as large as an entire continent.

Examples of stochastic broadcasting schemes are: probability-based, counter-based, and location-based broadcasting schemes [11]. Before rebroadcasting a message in probability-based schemes a node waits for a period of time called jitter or Random Assessment Delay (RAD), to minimize the chance of collision and to assist a better broadcast decision. Probability-based scheme controls rebroadcasts with fixed probability P. Nodes using counter-based schemes rebroadcast a message when the number of received copies of that message is less than some predetermined threshold value and this test is done after RAD (the waiting period of time) expires. In location-based schemes, a node rebroadcasts a message if the area within the node's range that is yet to be covered by the broadcast is greater than a threshold A.

III. Dynamic Counter-Based Broadcast

The fixed Counter-Based (CB) broadcast [12] was suggested to reduce the effect of excessive and redundant packet rebroadcasts incurred by conventional flooding. Counter-based broadcast incurs lower overhead compared to blind flooding while maintaining a good degree of packet propagation through the network. In this scheme, when a node receives a broadcast packet *p* for the first time, a counter *c* is initiated to count every receipt of *p* and a random assessment delay (RAD) is also initiated. RAD is a jitter randomly chosen between 0 and T_{max} seconds, where T_{max} is the maximum time delay. This delay is necessary for two reasons. First, it allows nodes adequate time to receive redundant packets and assess whether to rebroadcast. Second, the randomized scheduling prevents collisions [22]. As soon as the RAD timer expires the counter *c* is compared against a predefined threshold value *C*. If $c > C$ the packet is dropped, otherwise it is rebroadcasted. When *C* is large this scheme reduces to blind flooding.

Assigning the same threshold value to all network nodes, as in the fixed counter-based broadcast results in poor distribution of the threshold values. Mainly, using small threshold values would aid in greater packet savings, but this may affect reachability especially in sparse networks. Alternatively, larger threshold values are beneficial in sparse networks, but can unnecessary swamp a denser network with unneeded redundant packets in a flooding-like manner. Particularly, the aim is to achieve some balance between saving and reachability to reduce the chance of a node located in a dense region rebroadcasting a received message, while increasing the chance of rebroadcasting for nodes within a sparse network area.

The Dynamic Counter-Based broadcast (DCB) scheme proposed in the MANET context [14] aims at significantly reducing communication overhead even more than CB while still achieving reachability comparable to that of flooding. To achieve this, it utilises neighbourhood information, specifically by using the number of current neighbours to select the most suitable counter threshold. The number of surrounding neighbours (***n***) that a node has at a given time is monitored by periodic exchange of 'Hello' packets among neighbouring nodes. This aids a sensible selection of the threshold value, enabling adaptability to the fluctuating network densities that occur in highly mobile networks namely VANETs.

The DCB broadcast algorithm is an enhancement to the CB algorithm and works in a similar fashion but with an addition of smart threshold selection assisted by the node's local neighbourhood information.

Considering the fact that sparse networks require a higher chance to rebroadcast than dense networks. This can be implemented in DCB by utilising a sliding scale mechanism centred at the expected average number of neighbours. This would slide the threshold value *C* by a scale *s* amount to adapt to network density. A broad sensitivity analysis of the scale size *s* was carried out to prove that 3 is the best candidate for the scale size *s,* providing a sliding mechanism centred at 7 as illustrated in Figure 2.

The DCB proposed in this paper an enhancement to the algorithm implemented in [14] introducing the sliding window concept facilitating a more dynamic selection of the threshold value. This algorithm works as follows: when receiving a broadcast packet for the first time a node sets RAD, which is randomly chosen between 0

```
DCB_Broadcast_Algorithm

Pre: a broadcast packet p at node X is heard.
Post: rebroadcast the packet or drop it, according
to the algorithm

1.  Get degree n of node X
2.  c = 1
3.  i = 1
4.  Set RAD
5.  While (RAD) Do
        If (same packet heard) Increment c
6.  End while (RAD)
7.  If (n <= s) C = C2
8.  While (i > 0) Do
              if ((n > s*i) AND(n <= s*(i+1))
                 C = C2-1
                 If (C < C1)
                         C = C1
                 Goto End while (i)
              End If
              i = i + 1
9.  End while (i)
10. If (c > C)
       drop packet
       Exit ACB_Broadcast_Algorithm
11. End If
12. Submit the packet for transmission
End DCB_Broadcast_Algorithm
```

Figure 1: The Dynamic Counter-Based broadcast Algorithm

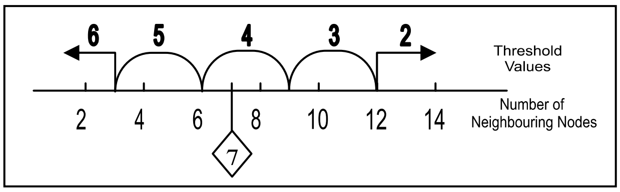

Figure 2: The DCB sliding scale concept

and T_{max} second and initiates the counter to one. During RAD, the counter is incremented by one for each redundant packet received.

Following, the appropriate threshold value is selected according to the node local neighbourhood information. That is, the node checks the number of neighbours' n against the scale size s. If $n \leq s$, (错误!未找到引用源。, line 7) then the neighbourhood is considered very sparse and C_2 is selected as the threshold value, otherwise the *sliding scale* loop shown in Figure 1, line 8 is executed, where n and s are the current number of neighbours and the scale size respectively.

Additionally, the values C_1 and C_2 are selected in a way that considers the expected additional coverage EAC. That is, C_2 (sparse network threshold) should be in a way larger than C_1 (dense network threshold) in order for the node to have a higher chance to rebroadcast in a sparse area, given that the EAC of a sparse network is higher than that of a dense network.
Lastly, (line 10, Figure 1) the counter is checked against the threshold value; if the counter is less than or equal to the threshold, the packet is rebroadcast. Otherwise, it is simply dropped.

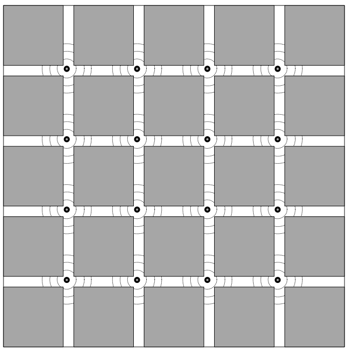

Figure 3: City model Illustration

IV. METROPOLITAN NETWORK MOBILITY STUDY

Studying VANETs in real test beds is preferable if not for the physical, logistic, economic and technological difficulties. Another feasible alternative is the study by simulation feeding the simulator with mobility models that are purely synthetic, mathematically calculated and generated, or based on real mobility traces [16]. Multiple factors are to be considered for a VANET simulation to be constructed. One is high speed vehicles moving in restricted lines, streets and lanes, with buildings blocking or hindering the transmission from travelling in the line of sight. In this paper the DCB algorithm study is carried out within two VANET models namely, highway and city. In the former model vehicles commute in highways with a maximum speed of 70km/ hour along streets in an open plane terrain. Additionally, vehicles are able to communicate freely along the line of sight with no obstacles or buildings. In the latter model, city, buildings and other obstacles often separate streets; therefore, there is not always a direct line of communications between nodes. That is, nodes can only communicate with nodes on the same street and with reachable relays at the corner of each street, Figure 3. The incorporation of relays facilitates vehicle-to-roadside communication as well as vehicle-to-vehicle communication patching the network-partitioning problem.

Figure 3, represents an illustration of the city model, where the solid gray blocks represent buildings, the dots at the cross points represent the relays and circles around each dot represent the transmission range of each relay's transceiver. The streets, the white areas between buildings, are the paths that nodes move on and it is the only way that the transmission can travel along. This restriction presents a great communication challenge for nodes employed in this model.

A. Simulation Environment

The metropolitan network study is implemented using the widely used network simulator ns-2 [17]. Nodes move within the network in a map similar to Figure 1 in streets and lanes. A node is allowed to move straight, right or left with a probability of 0.5, 0.25 and 0.25 respectively in pattern similar to the Manhattan Mobility Model [18]. In this paper three schemes are implemented and compared in the VANET context: dynamic counter-based broadcast, fixed counter-based broadcast and flooding referred to by: DCB, CB and flooding respectively.

The conducted simulation system settings include the study of 12 networks each having 25, 50, … 300 nodes with steps of 25 nodes. Nodes considered are identical mobile nodes operating in a flat area of size 1000m x 1000m. For all simulated scenarios the simulation runs for 900 seconds to avoid immature simulation termination and to keep simulation time at a manageable level. Each node represents a communication device equipped with IEEE 802.11b wireless transceiver and has a transmission range of 250m/ 150m. In reality, radio rays propagate in a non-linear fashion, as they are obstructed by environmental obstacles causing reflection or refraction [19]. Thus, this research considers a two-ray propagation model with the received signal consisting of two components: the line of sight ray and a reflected ray, which is the transmitted signal reflected off the ground. In this model, as the distance increases between the transmitter and the receiver, the resultant ray power would decay in an oscillatory fashion [20] which gives more accurate prediction at long distances than the free space model, which is another propagation model implemented and available within the network simulator, ns-2 [21].

To establish the results' statistical confidence several random topologies are run for each simulation. It was observed that the means of 30, 40 and 50 trials are within the same confidence interval of 95%. However, the mean values of 30 and 35 trials are almost the same. Consequently, our statistics were collected using a 95% confidence level over 30 randomly generated topologies. The error bars in the graphs represent upper and lower confidence limits from the means and in most cases they have been found to be fairly small so that they are obscured by the data series marker itself. Other simulation parameters are defined in Table I.

TABLE I:

SIMULATION PARAMETERS

Parameter	***Value***
Simulator	ns-2 version (2.33)
Network area	1000 x 1000 meter
Maximum speed	70 and 30 km/ hour
Transmission range	250 and 150 meters
Simulation time	900 sec
Number of trials	30
MAC layer protocol	IEEE 802.11b
Channel bandwidth	11Mb/sec
Confidence interval	95%

B. Performance Metrics

Performance metrics selected are used to measure the superiority and efficiency of the network performance. Also they are designated to enable comparing our algorithm to other related algorithms [12]. The performance metrics are summarised as follows:

a) *Collision rate*: is the total number of packets dropped by the MAC layer as a result of collisions per unit time.
b) *Saved Rebroadcast*: defined as $(r - t)/r$, where r is the number of hosts receiving a broadcast message, and t is the number of hosts that actually retransmitted that message.
c) *Reachability*: is the percentage of nodes receiving the broadcast packet over the total number of mobile nodes that are reachable directly or indirectly.

V. ANALYSIS AND RESULTS

This section presents the results and analysis of the network study under two models, namely the highway and the city models.

A. The Highway Model

This part carries out the study and analysis of nodes commuting within a highway scenario. Nodes commute within streets using a transmission range of 250m and a maximum speed of 70km/ hour. Moreover, variable network sizes are considered while maintaining other network parameters fixed. Among the fixed network parameters is the traffic load having an injection rate of 4 packets/ sec.

1) The Highway Model: Collision Rate

The average collision rate serves as an indication to scheme efficiency. Lower collision rates indicate a higher success at delivering a packet to its destination.

Figure 2 shows a clear relation between the number of nodes in a network and collision rate, where increasing the former increases the latter. This relation is apparent with flooding in a network with more than 100 nodes as collision rate increases dramatically with the increase in the number of nodes. This increase is less sharp with CB and DCB. The CB scheme scores a sharp increase in collision rates at networks of more than 200 nodes compared to a slight increase in DCB collision rate. This is because nodes implementing the DCB scheme incorporate a dynamic threshold assignment adaptable to the actual number of surrounding neighbouring nodes, inhibiting excess broadcasts of redundant packets resulting in fewer collisions.

2) The Highway Model: Saved Rebroadcast

The number of saved rebroadcast packets is among the most important metrics signifying the efficiency of a scheme.

Figure 5 shows the saving behaviour of the three considered schemes, with flooding (by definition) having no saving at all. The figure also shows that the amount of saving with low number of nodes (25 nodes) is around 18 % for DCB and CB. The amount of saved rebroadcast increases for both schemes with the increase of DCB slightly higher than that of CB. The benefit in saving becomes more apparent at networks of 100 nodes, scoring a saving of 60% and 70% for CB and DCB respectively. With networks of a higher density (200 nodes) CB savings start to collapse, decreasing from 60% to 30% when network size increases from 200 to 300 nodes respectively. As the nodal density becomes higher, the number of received packets becomes even more. Nodes implementing the CB scheme would suffer from a static criterion that results in rebroadcasting the high amount of received packets resulting in fewer savings. However, this is not the case with the DCB as it scores even more savings with larger networks, increasing savings from 80% to 90% as the network size increases from 200 to 300 nodes. This suggests significant scalability advantage of DCB.

3) Highway Model: Reachability

As Figure 6 show, reachability of all schemes are affected at networks of 25 to 50 nodes as the network connectivity suffers with such a very low nodal density. In networks with 50 to 100 nodes, all schemes scored a reachability of around 100%. With networks of more than 100 nodes, flooding reachability starts degrading until it reaches 40% in networks of 300 nodes. This is due to the higher collision rate resulting from the flooding behaviour of retransmitting every received packet with no conditions or sensitivity to nodal density. On the other hand, the performances of DCB and CB continue at its optimum until at network densities of 225 nodes when the CB reachability starts degrading. This reduction in CB's reachability is expected as the CB's collision rate, Figure 4, increases sharply within networks of 225 nodes and above, resulting in more packet loss. However, the DCB reachability continues to be around 100% even in dense networks having more than 225 nodes. This is related to the robust rebroadcasting decision making based on current local neighbouring density. With DCB Scoring high saved rebroadcast refraining from excess transmission, Figure 5 while maintaining the best possible reachability, Figure 4, DCB proves superiority over existing broadcasting schemes.

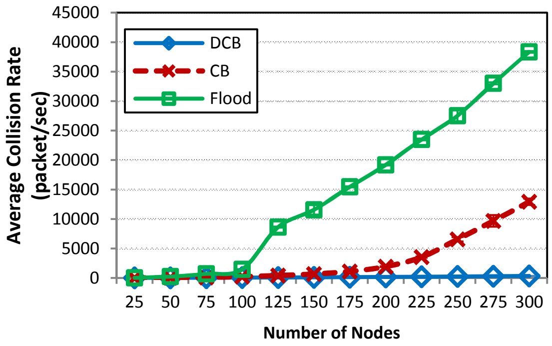

Figure 4. Highway model: collision rate vs. number of nodes

B. *The City Model*

The following presents the network study under the city model constrains such as a maximum nodal speed of 30km/ hour applying practical city centre speed limits. 12 network sizes are considered while maintaining other network parameters fixed. Same as the highway study, the traffic load have an injection rate of 4 packets/ sec.

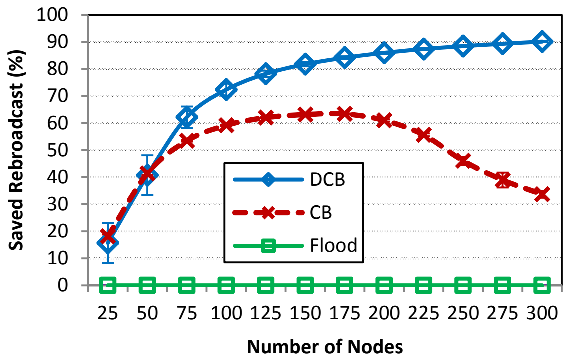

Figure 5. Highway model: Saved rebroadcast vs. number of nodes

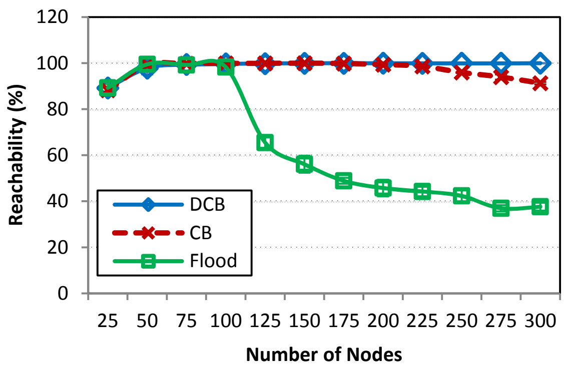

Figure 6. Highway model: reachability vs. number of nodes

1) *The City Model: Collision Rate*

Figure 7 illustrates the relation between collision rate and number of nodes. Increasing the number of nodes while maintaining other network parameters, results in an increased collision rate. This increase in collision rate is more apparent with flooding as the collision increases sharply in networks of more than 175 nodes. However, the same behaviour of sharp increase in collision rate started at smaller networks of 100 nodes for flooding in the highway scenario, Figure 4. This is because the highway model is implemented in an open space with no obstacles, enabling for even more collisions than that of the city scenario. CB's collision rate is increasing slightly with the increase in the number of nodes in the network. This is not the situation with the highway scenario where the CB's average collision rate increases sharply with networks of more than 200 nodes. The DCB's increase in collision rate is more subtle than that of CB, implying better scalability in both highway and city scenarios.

2) *The City Model: Saved Rebroadcast*

The level of saved rebroadcast, illustrated in Figure 6, generally increases with the increase in the number of nodes. As the figure shows, CB and DCB savings are affected by the network partitions for networks having 25 nodes. All schemes saving at 25 nodes is around 2% as opposed to all schemes savings at the highway model scoring around 20% at the same network size.

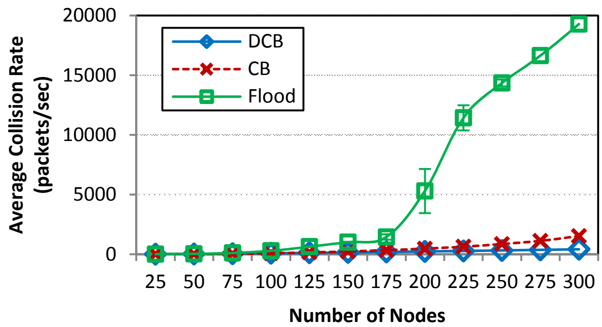

Figure 7. City model: Collision rate vs. number of nodes

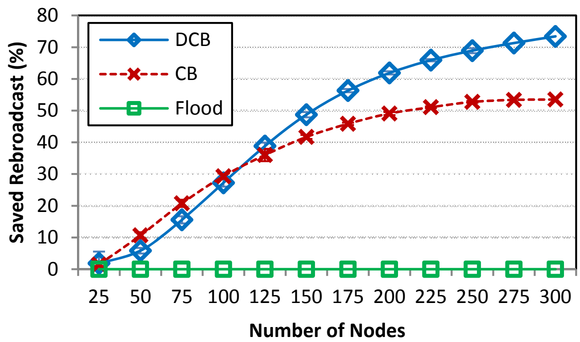

Figure 8. City model: Saved rebroadcast vs. number of nodes

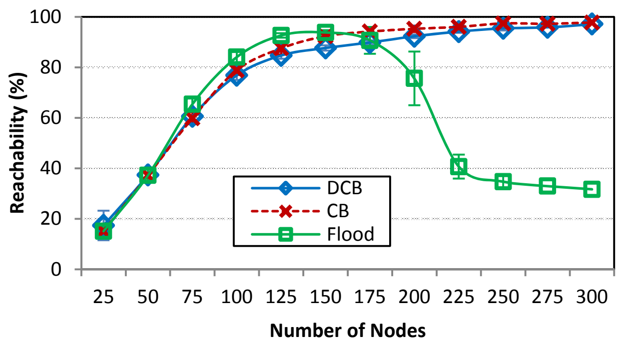

Figure 9. City model: reachability vs. number of nodes

In networks of 25-100 nodes the level of CB's saved rebroadcast is slightly better than that of the DCB; this is because DCB threshold assignment is dynamic, assigning high threshold values when the number of reachable neighbouring nodes is relatively low, allowing for more rebroadcasts (less saving). This is opposed to the fixed-threshold value used by the CB scheme, inhibiting more packet rebroadcasts at networks of 25 to 100 nodes. Within networks of more than 100 nodes the DCB saving starts to overcome that of CB. This is due to the dynamic technique accommodating and sensing network density to decide for an appropriate threshold value inhibiting unwanted packets from being rebroadcast to the communication medium. The saving continues to increment until it reaches around 70% and 50% for DCB and CB respectively at networks of 300 nodes. Generally, comparing the amount of saving under this model to that of the highway model, Figure 5, reveals that schemes implemented under the city model score fewer savings. This is associated with the network partitions in the city model that result in fewer reachable neighbours and fewer received packets, which increases the likelihood of the threshold value not to be exceeded by the number of received packets, hence, rebroadcasting a received packet instead of saving it.

3) The City Model: Reachability

Studying the different schemes under the city model, Figure 9, reveals how hard it is to reach maximum reachability with network partitions and node separation. While in the highway model, Figure 6, networks reach maximum reachability 100% though having 50 nodes only. Reachability in the city model barely reaches its maximum with 300 nodes in the network, proving that network partition is the worst hindrance to full network reachability. Network partitions and low nodal speeds in the city model make it hard for packets to reach some parts of the network, leading to poor reachability. Nevertheless, it is worth mentioning that flooding shows a slightly better performance of around 5% at densities of 75-125 nodes. This is linked to the fact that the other schemes impose some restrictions on the rebroadcast of a received packet resulting in a little loss of reachability in this specific density of 75 to 125 nodes, at this partitioned city model. The sharp decrease in flooding reachability at networks of 175 nodes may be understood by considering the sharp increase in collision rate at networks of the same size, Figure 5.

VI. Conclusions and Future Directions

This paper described the performance of the DCB broadcast scheme under two vehicle models, the highway and the city centre. Both models impose some restrictions on the vehicle's maximum speed and movement. While the highway model employs an open plan terrain with no obstacles, the city model incorporates the existence of buildings that separate each street from the other, resulting in higher fragmentation and network partitions. Compared to the flooding and the fixed counter-based broadcast schemes, simulation results using the highway model have revealed that DCB can improve saved rebroadcast up to 60 % compared to the counter-based and 90% compared to flooding even under high density, and high mobility conditions. Employing the city model, the amount of improvement in the DCB saved rebroadcast was 20% over CB and 70% over flooding. With DCB Scoring high saved rebroadcast refraining from excess transmission, while maintaining the best possible reachability, it proves superiority over existing broadcasting schemes. It would be an interesting continuation to this work to apply our broadcasting scheme into one of the well known routing protocols in VANETs to measure the efficiency of this scheme in the routing operation.

References

[1] T. A. Lasky and B. Ravani, "A review of research related to automated highway systems," *Federal Highway Administration*, Davis, CA, 1993.

[2] H. Hartenstein and K. Laberteaux, *VANET Vehicular Applications and Inter-Networking Technologies*: *Wiley*, 2010.

[3] ITS Japan. (15 September 2012). [Online]. Available: www.its-jp.org/english

[4] ITS America. (15 September 2012). [Online]. Available: www.itsa.org

[5] ERTICO, ITS Europe. (15 September 2012). [Online]. Available: www.ertico.com

[6] S. Tayal and M. R. Tripathy, "VANET-challenges in selection of vehicular mobility model," in *Second International Conference on Advanced Computing & Communication Technologies*, Rohtak, India, 2012, pp. 231-235.

[7] B. A. Fette, *Cognitive Radio Technology*, Second ed.: Academic Press, 2009.

[8] M. Amadeo, C. Campolo, and A. Molinaro, "Enhancing IEEE 802.11p/WAVE to provide infotainment applications in VANETs," Ad Hoc Networks, 08 October 2010.

[9] D. Lang, "Routing protocols for mobile ad hoc networks: Classification, evaluation and challenges," Saarbrücken: VDM Verlag Dr. Müller, 2008.

[10] H. Hartenstein and K. P. Laberteaux, "A tutorial survey on vehicular ad hoc networks," *IEEE Communications Magazine*, vol. 46, pp. 164-171, 2008.

[11] T. Yu-Chee, N. Sze-Yao, and S. En-Yu, "Adaptive approaches to relieving broadcast storms in a wireless multihop mobile ad hoc network," *IEEE Transactions on Computers*, vol. 52, pp. 545-557, 2003.

[12] T. Yu-Chee, N. Sze-Yao, C. Yuh-Shyan, and S. Jang-Ping, "The broadcast storm problem in a mobile ad hoc network," *Wireless Networks*, vol. 8, pp. 153-167, 2002.

[13] P. Rogers and N. Abu-Ghazaleh, *Towards Reliable Network Wide Broadcast in Mobile Ad hoc Networks*, 2004.

[14] S. O. Al-Humoud, L. M. Mackenzie, and W. Vanderbauwhede, "Dynamic counter-based broadcast in MANETs," in The *5th ACM International Workshop on Wireless Multimedia Networking and Computing, WMuNeP'09*, Tenerife, Spain, 2009.

[15] S. O. Al-Humoud, L. M. Mackenzie, and M. Ould-Khaoua, "Threshold and RAD analysis of adjusted counter-based broadcast in MANETs," *International Journal of Simulation Systems, Science & Technology*, 2009.

[16] J. Harri, F. Filali, and C. Bonnet, "Mobility models for vehicular ad hoc networks: a survey and taxonomy," *IEEE*

Communications Surveys & Tutorials, IEEE, vol. 11, pp. 19-41, 2009.
[17] The Network Simulator ns-2. (15 September 2012). [Online]. Available: www.isi.edu/nsnam/ns
[18] F. Bai, N. Sadagopan, and A. Helmy, "IMPORTANT: An evaluation framework to study the Impact of Mobility Patterns on RouTing in Ad-hoc NeTworks," University of Southern California 2005.
[19] A. Goldsmith, *Wireless Communications,* Cambridge University Press, 2005.
[20] T. S. Rappaport, *Wireless Communications Principles and Practice*, Second ed.: Prentice Hall, 2001.
[21] Ns Notes and Documentation. (15 September 2012). [Online]. Available: www.isi.edu/nsnam/ns/doc
[22] W. Brad and C. Tracy, "Comparison of broadcasting techniques for mobile ad hoc networks," *in The 3rd ACM international symposium on Mobile ad hoc networking and computing*, Lausanne, Switzerland, 2002.

Sarah Al-Humoud is an assistant professor at the department of computing science at Imam University, Riyadh, Saudi Arabia. She graduated in 2011 from University of Glasgow, United Kingdom having a PhD in Computing Science in mobile and wireless networks. She is currently appointed as the vice dean of the newly formed Deanship of Creativity, Talent and Excellence at Imam University, Riyadh. She holds a B.Sc. with an honour degree in Computer Applications and a M.Sc. in Computing Science. She Joined the University of Ulm, Germany for the XtreemOS Summer School, 2010. She also joined Ilmenau University of Technology, Germany for the Multicopter Programming Camp, 2011.

Dr. Sarah is the vice president of the women's committee of the Saudi Association of Computing, a member of the IEEE and Women in Wireless society.

Lewis Mackenzie is a Senior Lecturer in Computing Science and a member of the Embedded Systems and Networks group. His teaching in recent years has been primarily in data communications, networks and computer systems. His research interests are in mobile ad hoc, vehicular and wireless sensor networks, advanced computer architectures and simulation. He is also interested in physics of computing, quantum computing and philosophy of science and has recently co-authored a book covering topics in these areas. Within the School he is convener of the IT Committee and works closely with the Systems Team on equipment and IT service provision for both staff and students. He is also an undergraduate Adviser of Studies. Prior to joining the School, he worked for a time as a lecturer in the then Department of Natural Philosophy at Glasgow University where he led the development of a dedicated multicomputer for diagonal sing nuclear shell model Hamiltonians. His interest in multicomputer design and advanced architectures evolved from this base. He holds a BSc in Mathematics and Natural Philosophy and a PhD in Physics.