Fuzzy Logic-Based Congestion-Aware Geographical Routing (CAGR) for Vehicular Ad-Hoc Networks (VANETs)

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***Abstract* — Vehicular Ad hoc Networks (VANETs) is usually grouped with other similar networks types such as Mobile Ad hoc Networks (MANETs) and Wireless Mesh Networks (WMN). All of these types of networks are characterized as self-configuring and infrastructure-less. However, the vehicular nodes in a VANET are highly mobile and the corresponding communication protocols are specified to work up to speeds of more than 100 kph. In response to the communication requirement of VANETs as the network environment in Intelligent Transport Systems (ITS), the IEEE conceptualized the WAVE (Wireless Access in Vehicle Environment) System Architecture. One of the fundamental protocols behind WAVE is 802.11p, which is an enhancement of the 802.11 standard used in WiFi. While 802.11p enables inter-vehicle communication (IVC), especially neighboring vehicles, the communication protocol to use in sending traffic to and from a final destination, such as a back-end infrastructure or portal, is an open research. Two of the leading recommendations are (1) to use the cellular network and (2) to deploy a large-scale WAVE Roadside Units (RSU) infrastructure. In addition, there have been research initiatives to use the mobile vehicular nodes themselves to carry the traffic to and from the backend infrastructure. This involves multi-hop routing by relaying through the mobile nodes until an entry/exit point to the backend infrastructure is reached. This research focuses on multi-hop routing through the VANET nodes or relays with two key considerations: avoiding network traffic congestion and utilizing the geographical location of the neighboring nodes to enhance the wireless link quality. Fuzzy logic is used to make routing decisions based on these multiple metrics or constraints. Furthermore, heuristics is employed for the prediction of future received signal strength in a highly mobile fading channel to augment the fuzzy decision.**

***Index Terms* — VANET, MANET, vehicular ad hoc network, mobile ad hoc network, multi-hop routing, congestion, geographical routing, fuzzy logic**

I. INTRODUCTION

VEHICULAR AD HOC NETWORKS (VANETs), as a class of mobile ad hoc networks (MANETs), present unique challenges to mobile wireless communications. The vehicular nodes move at much higher speeds than other types of mesh networks involving devices such as laptops or wireless sensors. Also, currently deployed mobile networks involve a mobile node and a stationary base station or access point. The same can be said for VANET vehicle-to-infrastructure (V2I) communication where the vehicles communicate with roadside infrastructure. However, vehicle-to-vehicle (V2V) communication involves two high-speed mobile vehicular nodes.

The conception of VANETs is directly related to the Intelligent Transportation Initiatives in the US which started since at least the early 1990's. The rationale behind the concept is to automate the interactions among vehicles and infrastructure to achieve high levels of security, comfort, and efficiency. Communications, in general, and networking, in particular, have been essential elements in the evolution of these systems. The IEEE has developed a system architecture known as WAVE to provide Wireless Access in Vehicular Environments. Collectively, IEEE 802.11p, an extension of the more popular IEEE 801.11 wireless LAN standard, and IEEE 1609.x compose the WAVE system architecture [1].

The benefits of V2V communication in transportation safety are numerous. For example, wireless communications between vehicles enable them to maintain safe distance, to warn each other of potential dangers, to give signals even when visibility is poor, to convey accident information to other neighboring cars, or to provide traffic situation [3]. A doctoral thesis [3], enumerated the advantages of V2V communications, which are (i) allow short and medium range communications, (ii) present lower deployment costs, (iii) support short messages delivery, and (iv) minimize latency in the communication link. On the other hand, V2V communications present the following shortcomings: (i) frequent topology partitioning due to high mobility, (ii) problems in long range communications, (iii) problems using traditional routing protocols, and (iv) broadcast storm problems in high density scenarios [3].

Aside from confusing VANET with low-speed MANETs or wireless mesh networks (WMN), another common dilemma the choice of communication protocol or standard to follow in its implementation [4]. In the 2011 IEEE Vehicular Networking Conference, the topic for panel discussion was "LTE (or the 4G 4th Generation Cellular Standard) vs IEEE 802.11p – which technology to go for?" The result of the poll questions is that majority of the participants believe that (i) 802.11p, not LTE, will be used for safety applications, (ii) LTE, not a network of 802.11p roadside units (RSUs), will be used for connection to backend infrastructure, (iii) the 802.11p system offers the better scalability to full-deployment scenarios of vehicular communication systems, and (iv) LTE is more mature or deployment-ready [5]. Far from pitting one technology or organization from another, the result of the poll just shows how these two technologies can complement each other. After the WiMAX or WiFi vs 3G debates, we have come to realize when to use one technology over the other in an environment of coexistence. WiFi became ubiquitous because of the high data rates which it offers at the last-mile. The success of cellular 3G is due to its proven mobility in its core network. WiMAX is used for long-range, fixed or nomadic wireless access but its bet on a Mobile IP core network to address mobility never materialized. Thus, one might expect that the future VANET, in order to address the needs of an Intelligent Transport System, will be a mix of suitable communication technologies.

While the technology to use for V2I is still an open question, the WAVE System Architecture of IEEE has provision for V2I communications. IEEE WAVE seeks to enable both V2V and V2I communications by combining 802.11p with the standards from the IEEE 1609 working group. According to the 1609 working group, WAVE defines an architecture and a complementary, standardized set of services and interfaces that collectively enable secure vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) wireless communications. Together these standards are designed to provide the foundation for a broad range of applications in the transportation environment, including vehicle safety, automated tolling, enhanced navigation, traffic management and many others [6]. However, it is worth noting that WAVE aims to extend the range of the IEEE 802.11 standards up to 1000 meters. The 802.11p standard is focused on enhancing the physical and data link layers of the 802.11 protocols for vehicular scenarios. A key enhancement over the 802.11 standard is called OCB mode (Outside the Context of a BSS or Basic Service Set). OCB mode enables all the stations within the specified range to directly communicate with each other. Unlike the familiar WiFi infrastructure mode, or even ad-hoc mode, OCB mode has neither authentication/association procedures nor security mechanisms, thus the data exchange might be established in fractions of seconds [9]. . One can say that 802.11p has its hands full just to make V2V communications possible for two moving vehicles while utilizing, or one can say reusing, the WiFi 802.11 standard family. The 802.11p extensions focus mainly on improving signal properties and lowering the time needed for link establishment [9]. If two or more cars are within the specified distance, 802.11p should enable passing of information between them. Thus, V2V communication can be addressed.

V2I research seeks to answer the question of how to address communication beyond the neighboring vehicle as called for by emerging applications. Obviously, Internet access calls for communication between a vehicle and an outside infrastructure. One can also think of a scenario in which public vehicles need to report their current locations or situations to a centralized terminal. Here, information coming from a vehicle needs to reach the terminal through V2I communications. V2I research efforts include using cellular, WiMAX, and even fixed infrastructure to complete the end-to-end communication requirement. Even WAVE complements satellite, WiMax, cellular, and other communications protocols by providing high data transfer rates in circumstances where the latency in the communication link is too high, and where isolating relatively small communication zones is important [3].

The forte of 802.11p as a component of WAVE is in V2V communications. V2I may be implemented using any of the complementary technologies mentioned above. A clear illustration of how WAVE envisions V2V and V2I is Fig. 1 taken from [1]. The terms OBU, RSU, WBSS, and portal are shown. Thus, WAVE has provision for V2I and a complete all-WAVE implementation will incur building an infrastructure of roadside units (RSUs). However, the poll in the 2011 Vehicular Networking Conference suggests that a majority of its participants believe that LTE will be used for V2I, not 802.11p. On hindsight, with what happened to WiFi and 3G, this belief makes sense. WiFi succeeded in high data rate, short-range communications while 3G dominated mobility and longer-range communications. It's not far-fetched a scenario in which 802.11p is used for communication between vehicles while 4G

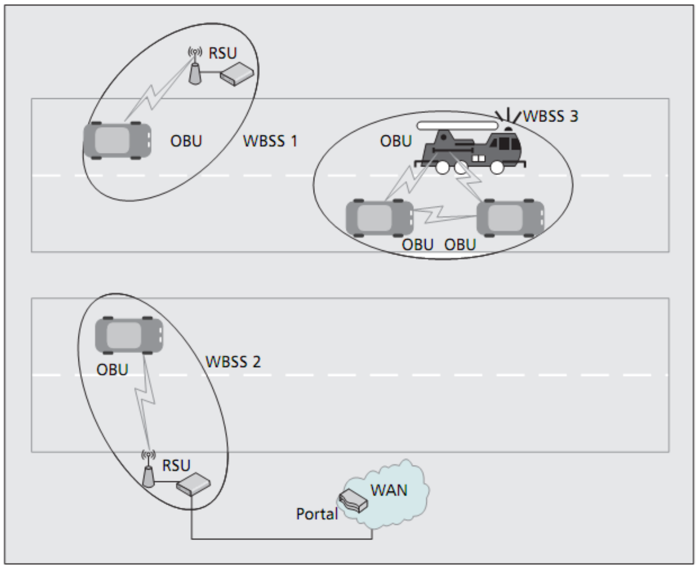

Fig. 1. Illustration of a WAVE system showing the typical locations of the onboard units (*OBUs*) and roadside units (*RSUs*), the general makeup of the WBSSs, and the way a *WBSS* (WAVE Basic Service Set) can connect to a WAN through a *portal*.

LTE is used every time a vehicle needs to communicate with an outside infrastructure.

There is one crucial factor that might just alter this 802.11p – 4G LTE picture. In order to guarantee network security and reliability, it may be preferable for the whole ITS network or VANET to be owned by a single entity – such as a highway toll operator or more likely the government. Here, using private telecommunication infrastructure, that is 4G LTE, is out of the question. For instance, if WAVE will be fully implemented for this VANET, roadside units (RSUs) will be deployed in places such as toll gates, traffic light poles or road signs.

Aside from the ITS ownership requirement, there are also technical reasons which keeps research into V2I protocols alive. Envision a scenario, in which V2V is feasible between two cars but only one of them can communicate with an RSU, isn't it efficient to pass information from the farther vehicle to the other vehicle and then to the RSU? Moreover, enabling end-to-end communication in such scenarios will also result more economical RSU infrastructure deployment, that is, fewer RSUs will be required especially for highways spanning thousands of kilometers. There are two main differing protocol stacks built on top of 802.11p to address V2V and V2I communications. The European Telecommunications Standards Institute (ETSI) ITS-G5 is a set of standards which define, among others, V2V communication protocols build upon IEEE 802.11p. The IEEE 1609 is a family of standards (IEEE 1609.0, 1609.1, 1609.2 1609.3, 1609.4, 1609.11, 1609.12) built upon IEEE 802.11p which defines an architecture and a complementary, standardized set of services and interfaces that collectively enable secure V2V and V2I wireless communications [9].

These two sets of standards are backed by large standardization bodies – ETSI and IEEE. Outside of their spheres, research into V2I communications is very much alive especially in the academic community. The key research area in these initiatives is the routing protocol to use in order to implement multi-hop connectivity over the VANET. As already emphasized, 802.11p will definitely address communication between neighboring nodes, that is over a single hop between two neighboring vehicles. The single hop means there is a radio link between the two neighbors and communication between them is feasible. Moreover, the single hop need not be a point-to-point connection between two vehicles. OCB mode supports simultaneous communication between multiple nodes within an area to communicate with each other. The issue VANET routing protocols are trying to address is how to send information beyond a single hop, that is how to route information from a source node to a destination using a path that traverses multiple radio hops. In VANET terminology, V2I is addressed by using multiple V2V links.

This research seeks to contribute to multi-hop routing protocols in order to address the need for V2I communications in a VANET using multiple, short-range V2V links. The key characteristic of this Congestion-Aware Geographic Routing (CAGR) protocol in contrast to other VANET routing protocols is that the decision of a node as to which neighbor to pass information to towards the destination is based on fuzzy logic with multiple constraints or inputs. The constraints, metrics, or inputs are (1) the *vector distance* of the current node from the neighboring node referred to the vector connecting the current node and the destination node and (3) the buffer occupancy of a neighboring node. Furthermore, a

In this paper, Section 2 cites related researches and gives a summary of VANET especially multi-hop connectivity routing protocols. Section 3 provides a description of the proposed CAGR protocol and describes fuzzy logic as a tool to assist VANET node routing decisions. Finally, Section 4 concludes the present paper, identifies future work and enhancements, and the next step of simulating CAGR in VEINS (Vehicles in Network Simulation), an open source framework for running vehicular network simulations based on OMNeT++, an event-based network simulator, and SUMO, a road traffic simulator.

II. Related Work

Countless numbers of routing protocols have been developed for MANETs, but many do not apply to VANETs [10]. VANETs are a separate class of MANETs because of their highly dynamic topology, intermittent connectivity, patterned mobility, propagation model, unlimited battery power and storage, and on-board sensors [10]. A survey of VANET routing protocols is provided by [10] . It gives references to surveys of MANET routing protocols as well. The current paper need not itemized the protocols in these surveys but only highlight the summary. Moreover, some VANET routing protocols which were not mentioned in the said survey will be discussed briefly since they are more relevant to the present research. Finally, this section will go through the latest developments in the efforts to incorporate 802.11p in the Linux kernel. This initiative to implement 802.11p in Linux will prove valuable in hastening the development of radio products with WiFi interfaces which support 802.11p. It is worth emphasizing that mainline research and industry trends favor implementing higher protocol stacks, whether IEEE 1609 or ETSI ITS-G5, and multi-hop routing protocols on top of the physical and data link layer standards of 802.11p.

The VANET survey [10] summary is reprinted here as Fig. 2. Topology-based routing uses the information about links or link states that exist in the network to perform packet forwarding. Geographic routing (position-based) uses physical neighbor location information to perform the same. Because link information changes in a regular basis in VANETs topology-based routing suffers from routing route breaks. For more detailed evaluation of the different types and sub-types of VANET routing protocols, one is referred to [10] and its list of references. Since the present paper falls under geographic routing, this type needs further explanation. Again [10] will prove useful here.

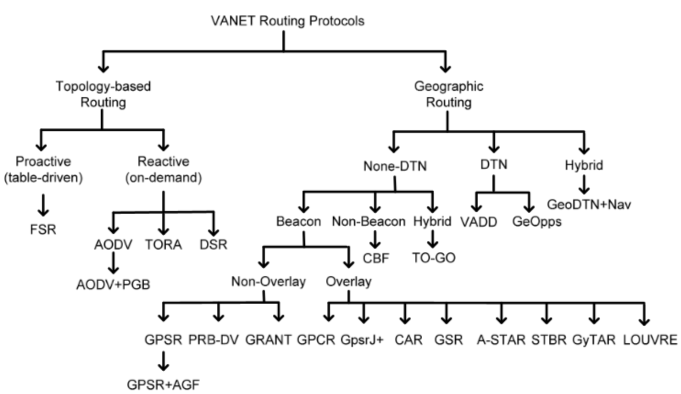

Fig. 2. Taxonomy of Various Routing Protocols in VANET

In geographic (position-based) routing, the forwarding decision by the current node is primarily made based on the position of a packet's destination and the position of the node's one-hop neighbors. The position of the destination is stored in the header of the packet by the source. The position of the node's one-hop neighbors is obtained by the beacons sent periodically with random jitter (to prevent collision). Nodes that are within a node's radio range will become neighbors of the node. Geographic routing assumes each node knows its location, and the sending node knows the receiving node's location using Global Position System (GPS) devices. Since geographic routing protocols do not exchange link state information and do not maintain established routes like proactive and reactive topology-based routings do, they are more robust and promising to the highly dynamic environments like VANETs. In other words, route is determined based on the geographic location of neighboring nodes as the packet is forwarded. There is no need of link state exchange nor route setup [10]. Thus geographic routing protocols are said to be stateless and a node need not concern itself with the end-to-end path between the source and the destination. A node's forwarding decision is based solely on the proper selection of the next-hop neighbor to whom a packet it is currently holding will be forwarded. One can see the obvious advantage of a stateless routing protocol when the nodes are highly dynamic as in the case of vehicles travelling on roads.

One paper [7] of particular interest to the current research proposes the Stability and Reliability Routing (SRR) protocol. The SRR protocol incorporates fuzzy logic with geographical routing when making packet forwarding decisions. The routing metrics or inputs to the fuzzy decision making system are direction and distance so that the best preferable neighbor around the current node is selected. As seen in Fig. 2, SRR was not included in the survey although it can be correctly categorized within the same taxonomy. The paper further proposes a mechanism to cache data packets once the network is disconnected and then switch back to SRR in a connected vehicular scenario. Vehicular traffic density is considered as an input when to estimate network dis-connectivity [7]. SRR is also compared to more well-known protocols in Fig. 2, such as Greedy Perimeter Coordinator Routing (GPCR) representing geographic routing and Dynamic Source Routing (DSR) under topology routing. SRR was shown to have significant improvements over these protocols particularly in dense traffic conditions.

In Fig. 2, geographic routing is sub-classified into three categories of non-Delay Tolerant Network (non-DTN), Delay Tolerant Network (DTN), and hybrid. The non-DTN types of geographic routing protocols do not consider intermittent connectivity and are only practical in densely populated VANETs whereas DTN types of geographic routing protocols do consider dis-connectivity. However, they are designed from the perspective that networks are disconnected by default. Hybrid types of geographic routing protocols combine the non-DTN and DTN routing protocols to exploit partial network connectivity [10].

The proposal of [7] falls under the DTN type since it handles two modes of vehicular traffic density. When inter-vehicle radio links are fully connected, SRR is used. When vehicles are disconnected, the current node queues up the packet, instead of simply dropping it, for another forwarding opportunity [7].

SRR is of special interest to the present paper because the proposed Congestion-Aware Geographical Routing (CAGR) also uses fuzzy logic for decisions on which neighbor node to pass the packet to. Moreover, CAGR benefits from the recommendations of SRR by combining the two metrics used in SRR – distance and direction – into a single vector distance metric. The other metric to the fuzzy decision engine, which differentiates CAGR from SRR, is the buffer occupancy of the neighbor nodes, giving CAGR awareness of node congestion. In SRR, when the fuzzy process yields identical results for two neighboring nodes, the choice between the two is randomized. In such scenario, knowing which of the two nodes can be a potential bottleneck is valuable. Thus, node buffer occupancy is included in the fuzzy decision of CAGR. Note that the closest to a Quality of Service (QoS) consideration in the survey of [10] is in Delay Tolerance. DTNs minimize packet losses. However, there was no mention in [10] of VANET routing protocols with QoS considerations. Still, this does not mean that QoS is not addressed in any literature since it is a central consideration at least in MANET papers such as in [12][13][14][15]. The present paper's CAGR aims to extend QoS considerations, particularly node congestion-awareness, for VANETs. Another key feature of CAGR, that of using heuristics to better estimate the wireless link or channel between neighboring nodes, will be discussed in detail in the succeeding section. This CAGR feature benefits from the work of Aguiar et al. [11] also discussed in some detail in Section 3.

Finally, this related literature section gives an overview of what may be considered as state of the art of VANET. There are lots of companies working on their own ITS VANET implementations and some are also using 802.11p as the foundation. However, as what happened with WiFi, its open-source implementations paved the way to making it available to billions of people around the world. Just this December 2014, a report was released by the Czech Technical University in Prague on the initiative to incorporate 802.11p into the Linux kernel [9]. This is a natural evolution of the mature 802.11 standards implementation in Linux. Linux-based routers and Android-based mobile devices with WiFi interfaces will naturally benefit from this development. The report by Lisovy et.al [9] ended with the following conclusion. While, a fully functional 802.11p is on its way to the mainline Linux kernel, a lot of work is still to be done to have a fully functional C2C (car-to-car) communication protocol stack for ITS. Possible future extensions are transmit power control in the 5 GHz band, support for ITS-G5 decentralized congestion control, inclusion of the 5.9 GHz band to the whole IEEE 802.11 subsystem, support for other frequency bands for research and development purposes, and adding support for OCB mode for other wireless NICS (network interface cards). Finally, to be able to operate a fully functional C2C communication stack for ITS the upper layer protocols are needed. This may lead to the Linux implementation of the ITS-G5 or IEEE 1609 protocol stack. From this assessment of the state of the art of VANET, at least from an open-source perspective, one may say that the door is wide open for V2I proposals, especially multi-hop connectivity and routing protocols.

III. Proposed Protocol: Congestion-Aware Geographic Routing (CAGR)

This section starts with a clarification as to where CAGR is placed in the taxonomy of routing protocols for VANETs (Fig. 2). CAGR is definitely a geographic routing protocol. Whether it is DTN or non-DTN can be said to depend on the actual implementation. In a delay-tolerant CAGR, the implementation will be similar to that of delay-tolerant SRR as in [7]. To address network dis-connectivity, when all of neighboring nodes are unreachable at the radio link level, the current node will cache the packet up to the limit of its own buffer and will release the packet when the network becomes connected, that is, when at least one neighboring node become reachable. As in SRR [7], this bridges the gap between connected and disconnected vehicular scenarios and the fundamental workings of the routing protocol remains intact. In contrast to DTN, a non-DTN version of CAGR means that a current node will simply drop packets when there is no connected neighboring node, leaving the task of reliable end-to-end connection for the upper layers of the protocol stack, such as TCP (Transmission Control Protocol). At face value, one may simply prefer a DTN over a non-DTN routing protocol. It should be mentioned, however, that there are applications which prefer real-time connectivity over reliable packet transfer, such as those utilizing UDP (User Datagram Protocol). In these applications, such as streaming audio or video, a delayed or buffered packet is as good as a dropped packet and continuity of the packet stream is more important than recovering lost packets. The succeeding discussion will describe in detail the design of CAGR with the provision that CAGR can be used as DTN or non-DTN.

Most routing protocols utilize hello messages as a way for a node to broadcast information to other nodes within its range. It is the contents of the hello messages which differ from one protocol to the other. In SRR [7], a vehicle can observe its neighbor's position and direction information through periodic hello packets from neighbors which contain those nodes' GPS information of geographic position and direction. Hello packets are received by other vehicles within a vehicle's communication range. CAGR adds to the content of the hello messages. Aside from GPS information, a node will also advertise its buffer occupancy. Buffer occupancy can be expressed as a percentage of the number of bytes available in a node's buffer memory with respect to the total buffer size as in [12].

In selecting the best neighbor among a number of possible next-hop neighbors, the proposed CAGR considers two metrics, or constraints in other literature: (1) the *vector distance* of the current node from a neighboring node referred to the vector connecting the current node and the destination node and (2) the *buffer occupancy* of a neighboring node. Thus, CAGR is a multi-constraint or multi-metric routing protocol. The first metric can be considered as an initial stab in optimizing the radio link for a hop while the second metric is used to estimate, and thus avoid, node congestion. The choice of these metrics has support in existing VANET or MANET routing protocol research. The vector distance is a composite of the distance and direction metric used in fuzzy-based SRR [7]. Buffer occupancy is also used as a metric in fuzzy-logic based MANET protocols as in [12], [14], and [15].

Fuzzy logic-based methods rely on the strength of fuzzy logic to handle imprecision and uncertainty. Similarly, the two metrics used in CAGR may conflict with each other resulting to uncertainty. Based on fuzzy logic, CAGR can select the best neighbor node as the next-hop by considering vector distance and buffer occupancy. There are existing VANET protocols which consider distance, mobility, and signal strength as metrics, such as FUZZBR [8]. In FUZZBR, the three metrics are the inputs to the fuzzy-based system. One might think that using these three metrics will provide a better assessment of the highly dynamic mobile fading channel. It is the view of the authors of the current paper that a more accurate channel estimation is desirable however, incorporating signal strength directly into fuzzy logic will tend to favor shorter hops since most of the time, shorter hops give higher signal strength readings. CAGR, like SRR [7], recognizes the fact that a shorter distance between nodes leads to high number of hops while the probability of link failure increases with longer distances. Thus, in the fuzzy rules, CAGR follows SRR in giving higher fuzzy score to intermediate distances. Thus combining this distance metric and fuzzy rule with a received signal strength metric will shift the balance toward shorter distances, unless significant effort is given to normalizing the signal strength reading with the distance. Instead of using signal strength as a metric, a heuristic approach is used. Section 3 will conclude with a discussion of how a heuristic approach can be used to better estimate the wireless channel condition. Before that, the following discussion details the fuzzy logic design for next-hop neighbor selection.

According to Wu et al. [8], a difference from classical set theory is that, in fuzzy set theory, elements have degrees of membership. By defining set membership as a possibility distribution, fuzzy set theory can represent incomplete or imprecise information. Based on fuzzy set theory, fuzzy logic deals with the concept of approximate rather than precise factors. Since fuzzy logic can handle approximate reasoning, which is similar to human reasoning, it has been widely accepted in industrial communities and used in many applications. In contrast to numerical values in mathematics, fuzzy logic uses non-numeric linguistic variables to express the facts. Fuzzy membership functions are used to represent the degrees of a numerical value belonging to linguistic variables. Typically, a fuzzy logic based system consists of three steps: input, process and output steps. The input step converts input numerical values to linguistic variables. The process step collects logic rules which are defined in the form of IF-THEN statements and applies the rules to get the result in a linguistic format. The output step converts the linguistic result into a numerical value. [8].

In selecting the next-hop and for each candidate neighbor node, the calculation steps are as follows [8]: (A large part of the fuzzy procedure used in this paper benefits from the advances of the work by Wu et al. [8])

- Step1: Fuzzification - Use predefined linguistic variables and membership functions to convert the vector distance factor and buffer occupancy factor to fuzzy values.
- Step2: Mapping and combination of IF/THEN rules - Map the fuzzy values to predefined IF/THEN rules and combine the rules to get the rank of the neighbor as a fuzzy value.
- Step3: Defuzzification - Use a predefined output membership function and defuzzification method to convert the fuzzy output value to a numerical value.

After calculating the score for all neighbors, the current node, or the sender, the node that has maximal score fitness value as the next-hop to whom a packet will be passed. End to end connectivity will be achieved using multiple hops with each node deciding on its next-hop from its candidate neighboring nodes until the destination node is reached. The same fuzzy logic-based process will run in each node in order to select the best neighbor as the next-hop.

The process of converting a numerical value to a fuzzy value using a fuzzy membership function is called "fuzzification". The fuzzy membership function of the vector distance factor is defined as in Fig. 3. The current sender node uses the membership function and the vector distance factor to calculate which degree the vector distance factor belongs to {Near, Intermediate, Far, Exact}. Vector distance will range from 0 to 1. Although mid-distance or intermediate distance is usually preferred, an exact value of 1, subject to minimal degree of error, is the best case scenario. A value of 1 for vector distance means that the end destination node is already a neighbor of the current node. In this case, the current node can opt to immediately pass the packet directly to the destination node or buffer it for some time when the buffer occupancy of the destination node is high.
(A case where the current node may select a different neighbor node instead of the direct hop to the destination node will be

explained towards the end of the current section as part of the heuristic approach in wireless channel quality estimation). Fig. 4 illustrates the concept of vector distance. Note that the vector distance is computed by referring the sender-neighbor vector to the sender-destination vector. First, the bearing of the two vectors ***SR*** and ***SD*** with respect to the North direction is computed from the coordinates (longitudes and latitudes) of the nodes. A bearing is a vector composed of the length or distance of the vector and the angle the vector makes with a reference line, which is the North direction. Then, an angle α is obtained by subtracting the angles of the two vectors. Finally, the vector distance factor is computed as in Equation (1), that is the magnitudes or distance of vector ***SR*** is divided by that of ***SD*** and then multiplied by cosine α.

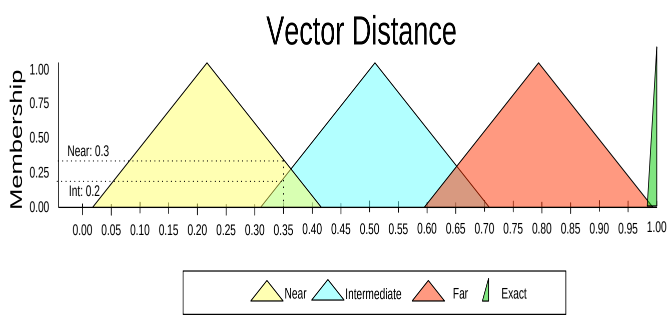

Fig. 3. Fuzzy Input Membership Function for the Vector Distance Factor and a Sample Fuzzification

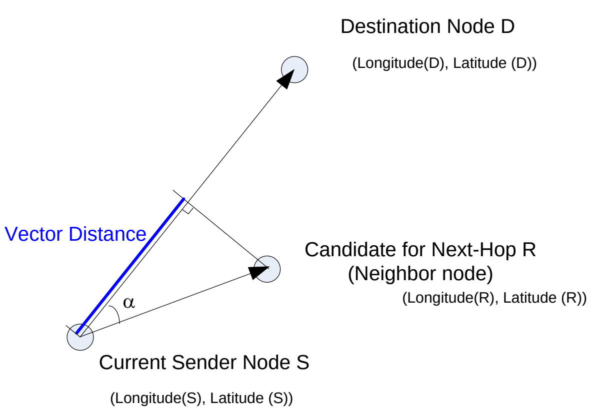

Fig. 4. The Vector Distance Factor

$$\text{Vector Distance Factor} = \frac{|\overrightarrow{SR}|}{|\overrightarrow{SD}|} \cos\alpha \qquad (1)$$

As shown in Fig. 3, when the vector distance factor is say 0.35, the vertical line showing this distance factor meets with "Near" and "Intermediate" at (0.35, 0.3) and (0.35, 0.2) respectively. It follows then that the fuzzy value is {Exact:0, Far:0, Intermediate:0.2, Near:0.3}. One characteristic, or can be considered as a disadvantage, of fuzzy logic is that setting the numerical values in the membership functions require expert knowledge of the system under consideration. Often, one will start with arbitrary values and tweak them using trial-and-error. A better approach is to tweak the initial values as simulation results come in. One can also go the extra mile by incorporating into fuzzy logic other soft computing technologies, such as neural networks in a hybrid neuro-fuzzy approach, to dynamically change the membership function values as the system learns about settings which will yield the best performance. Aside from the membership function values, another aspect of fuzzy logic which share the same characteristic is the rule base.

The fuzzy membership function of the buffer occupancy factor is defined as in Fig. 5. The current sender node uses the membership function and the buffer occupancy factor to calculate which degree the factor belongs to {Empty, Half, Full}.

Once the fuzzy values of vector distance factor and buffer occupancy factor have been calculated, the current sender node uses the IF/THEN rules (Table 1) to calculate the rank of each and every neighbor node. The linguistic variables of the rank are defined as {Perfect, Very Good, Good, Acceptable, Bad, Very Bad}.

In a rule, the IF part is called the "antecedent" and the THEN part is called the "consequent." Since there are multiple rules applying at the same time, one needs to combine their evaluation results. In [8], the Min-Max method is used. In the Min-Max method, for each rule, the minimal value of the antecedent is used as the final degree. When combining different rules, the maximal value of the consequents is used. Continuing the previous example, let the fuzzy value for the vector distance factor be {Exact:0, Far:0, Intermediate:0.2, Near:0.3}. Moreover, let the fuzzy value for the buffer occupancy factor be {Empty: 0, Half: 0.75, Full:0.25}.

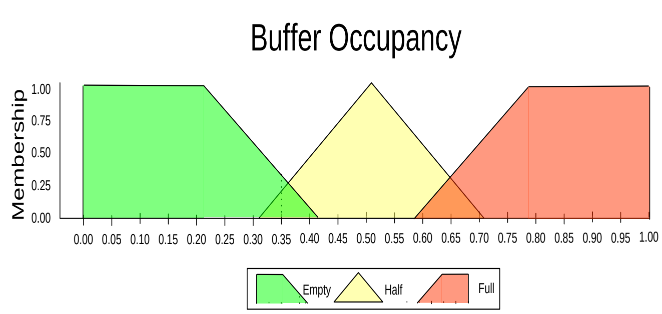

Fig. 5. Fuzzy Input Membership Function for the Buffer Occupancy Factor

	IF		THEN
Rule	Vector Distance	Buffer Occupancy	Fuzzy Score
1	Far	Full	Bad
2	Far	Half	Acceptable
3	Far	Empty	Good
4	Intermediate	Full	Acceptable
5	Intermediate	Half	Good
6	Intermediate	Empty	Very Good
7	Near	Full	Very Bad
8	Near	Half	Bad
9	Near	Empty	Acceptable
10	Exact	Full	Good
11	Exact	Half	Very Good
12	Exact	Empty	Perfect

Table 1. Rule Base or Knowledge Structure Based on Fuzzy Rules

In Fig. 6, these sample input fuzzy values are used for fuzzy rule evaluations. In this way, all rules are combined to give a fuzzy result.

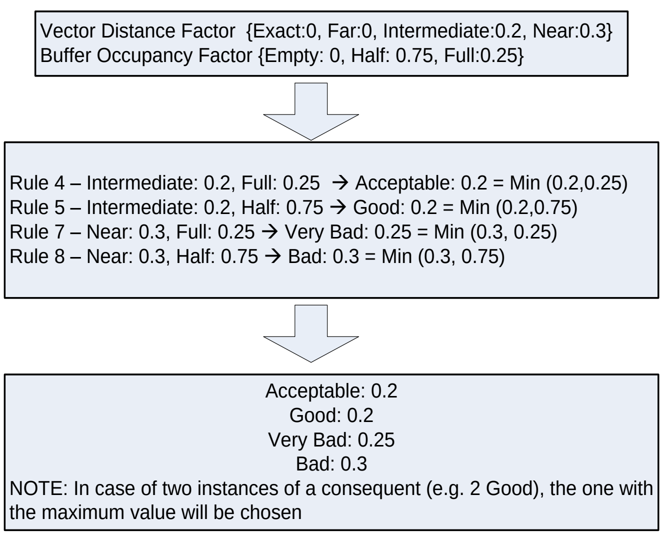

Fig. 6. An illustration of an example of a Fuzzy Rule Evaluation

As a last step in the fuzzy logic process, defuzzification is the process of producing a numeric result based on an output membership function and corresponding membership degrees. The output membership function is defined as in Fig. 7. Again in [8], the Center of Gravity COG) method to defuzzify the fuzzy result. The resulting shape in Fig. 7 was obtained from the fuzzy result (Fig. 6). If the function defining this shape is f(x), the center of gravity will be

$$COG = \frac{\int \mu(x)xdx}{\int \mu(x)dx}. \quad (2)$$

The abscissa or x-coordinate of the centroid will be the defuzzified value. This value is the final fitness score a neighbor of the current node which is a next-hop candidate. The higher the fitness score, the better the neighbor node will be as a next-hop candidate. The current sender node calculates a fitness value for each neighbor node and then selects the neighbor which has the maximal fitness value as the next-hop towards the destination node.

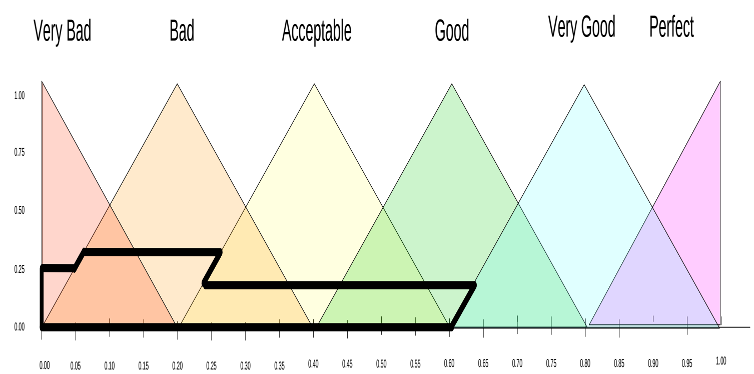

Fig. 7. Output Membership function and an example of the resulting shape of function f(x)

As a final note, the present research seeks to enhance estimation of the quality of a hop under the challenging condition of a highly mobile and frequently obstructed propagation channel. That is, the proposed CAGR protocol aims to enhance the estimation of a wireless link to augment current geographic routing methods. Instead of solely relying on distance between nodes, a heuristic approach is proposed to use received signal level in order to take into consideration the highly mobile channel and the possible obstructions between nodes.

With SRR [7], estimation of radio link quality depends only on distance and direction. However, it is not hard to visualize a situation where two neighboring nodes are of approximately the same distance from the current node and direction to the destination, based on GPS coordinates, but one has line-of-sight (LOS) while the other is faced with a non-LOS or obstructed channel. Definitely, a random choice between the two neighboring nodes will not work and there has to be a mechanism to choose the one with line of sight. Moreover, since the nodes are mobile, there should be some form of prediction of the future behavior of the wireless channel.

Heuristics are an important alternative to more complex predictors or algorithms [11] such as those incorporating digital maps to vehicular nodes to estimate the channel characteristics of an obstructed link. In Aguiar et al. [11], results show that, as long as the necessary prediction horizon does not exceed 2 ms, assuming the channel to stay constant leads to less than 15% capacity loss compared to the case when perfect channel prediction is used. When farther prediction horizons are needed, the moving average of the received signal should be used for channel prediction. The following three heuristics for the prediction of the received signal strength will be used [11].

- the signal will not change, i. e. the predicted value is the same as the last measured one
- the signal changes according to the average of an amount N of recent samples
- the signal changes linearly according to the trend of an amount N of recent samples

After using these heuristics to estimate the near future received signal level, the current paper proposes modifying the effective vector distance before its input to the fuzzy engine. The distance between nodes can be modified using the estimated received signal level using log-normal shadowing model:

$$PL(d)\,[dB] = PL(d_0) + 10 \times n \times \log \frac{d}{d_0} + X_\sigma \qquad (3)$$

IV. Conclusion and Future Work

Traffic applications such as traffic safety, cooperative traffic monitoring and control of traffic flow would become realities through the emergence of VANET – considered as the network environment of ITS [7]. A leading candidate for V2V communications in VANET is 802.11p. However, V2I communications standardization is an open research. Aside from the mainstream ETS ITS-G5 and IEEE 1609, research on multi-hop routing protocols for V2I communications is very active. The present paper proposes a Congestion-Aware Geographic Routing (CAGR) protocol based on fuzzy logic. Of immediate importance, is the simulation of CAGR in an environment such as VEINS (Vehicles in Network Simulation), an open source framework for running vehicular network simulations based on OMNeT++, an event-based network simulator, and SUMO, a road traffic simulator.

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