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Service-Oriented Delivery of ITS Content to Mobile Vehicles

M. Elshenawy and M. EL-Darieby
Software Systems Engineering, University of Regina, Regina, SK, Canada

***Abstract*— Wireless mesh networks (WMN) is poised to be a cost-effective platform for many municipal applications in public safety, business and entertainment. In this paper we present a service-oriented WMN-based platform for content delivery within Intelligent Transportation Systems (ITS) applications. An example ITS application would be to deliver content used for vehicle route guidance in emergency evacuation situations. The characteristics of ITS applications of higher vehicle speeds and of the limited coverage of WMN router causes more frequent handoffs which complicates content delivery over wireless mesh networks. Frequent handoffs mandate smaller handoff delay. Using standard IEEE handoffs may cause unacceptable interruption in content delivery. We propose a Service-Oriented mobility management protocol (SMMP) for ITS content delivery. Within the protocol, content is considered as services described by XML metadata files. The protocol takes advantage of a hierarchical organization of WMN routers to reduce the handoff delay. The quasi-stationary nature of WMN mesh routers enables the detection of the sequence of routers that a vehicle will be in connection with. SMMP provides to the travelling vehicles cached MAC addresses of WMN mesh routers to communicate with. Moreover, we study and present three different vehicular mobility management schemes and compare these to the standard IEEE 802.11 mobility management scheme. We evaluate the benefits of the proposed protocol and compared it to the traditional solutions using OMNET++ simulator. Our results show that using SMMP reduces handoff latencies and improves the overall network throughput at lower and higher vehicle speeds.**

***Index Terms*— Wireless Mesh Networks, Mobility Management, Handoff and Intelligent Transportation Systems**

I. INTRODUCTION

SEAMLESS transportation is one of the pillars of our societal and economical sustainability. Intelligent Transportation Systems (ITS) offers potential solutions to growing congestion problems in major urban areas. These solutions require distributing content to vehicles travelling on streets and highways. Examples of ITS contents include traffic information (e.g., congested areas, incidents, road closures, and camera images), roadside information (e.g., parking information, points of interests such as restaurants and gas stations, emergency evacuation plans as well as weather information.

ITS Content can be delivered to vehicles using vehicle-to-infrastructure wireless communications. Generally, the content is delivered to roadside infrastructure (aka Road-Side Units RSU) via a Content Delivery Network (CDN). Fig. 1 presents reference architectures for such system. Users, in travelling vehicles, request a specific piece of content from the nearest RSU. The request is forwarded and processed through the CDN and content is forwarded over the Internet back to the requesting RSU. There are generally many types of wireless infrastructure that can be used for ITS content delivery. Here, we focus on Wireless municipal Mesh Networks (WMN). Recent efforts are made to carpet cities with wireless broadband coverage using WMN because it is poised to be a key infrastructure for enabling new applications in public safety and entertainment. The wireless government report [3] lists 451 requests for proposal for municipal WMN deployments.

WMN consist of a set of self-configuring mesh routers that form and maintain a wireless infrastructure. They are typically deployed in a quasi-stationary manner, where some mesh routers are stationary. This wireless infrastructure enables routing of information in a multi-hop manner. WMN nodes comprise mesh clients and WMN Access Points (AP). Mesh clients can be cellular phones, as well as On-vehicle Board Units (OBU). WMN AP, also referred to here as RSU, can self-configure themselves to automatically build the wireless infrastructure that establishes and maintains mesh connectivity. A WMN AP typically provides access to a fixed structure network or to the Internet. A major advantage of WMN is that AP can share connections to the Internet. In other words, APs exchange information to identify their neighbours as well as to identify AP with direct connection to the Internet (a.k.a. gateways). WMN APs collaborate and forward collected data towards/ from gateways. WMN AP without a direct Internet connection can establish a multi-hop wireless connection to the gateways and hence to the Internet.

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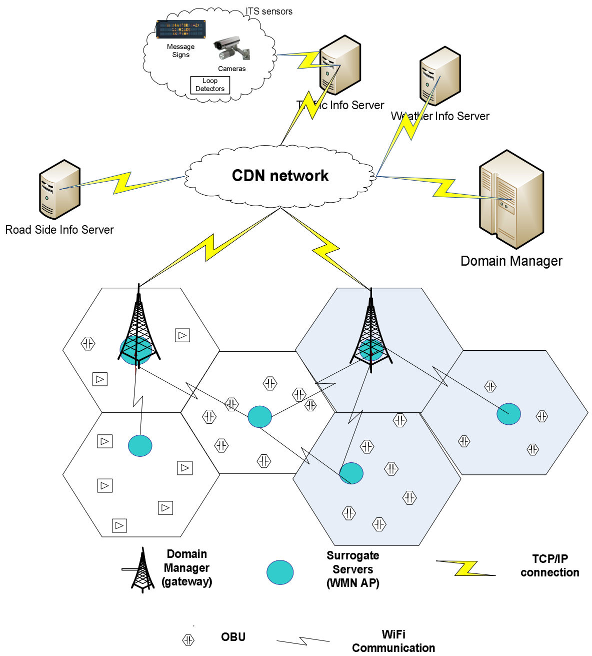

Fig. 1: A reference architecture for the proposed platform

This allows WMN AP to gather content from the CDN. This ITS content is then provided by WMN AP and is consumed by OBU.

A number of general requirements and characteristics are required for the proposed architecture. These characteristics include geographic coverage, cost-effectiveness, fault resilience, and privacy and security [1], [2], [5]. Here, we focus on designing an ITS CDN architecture that meet the following characteristics: 1) reliability: proposed architecture should implement efficient and transparent content sharing and delivery mechanisms that ensure that the content is always available; 2) mobility management: proposed architecture should enable seamless content delivery for vehicles while travelling along highways and streets; and 3) scalability: proposed architecture should be minimally affected by the increase in the number of nodes, the number of services, in the number of vehicles and the geographic area covered.

We propose and study such CDN architecture. The contributions of this paper are as follows:

1). We apply concepts from service-oriented computing to build mechanisms for content description, discovery and consumption. Within the network, content is considered as services that are described, advertised, discovered and consumed in a transparent manner through using XML-files. We assume a distributed and synchronized service registry maintained at APs.

2). We propose different mechanisms for managing content delivery with vehicular mobility. Each WMN AP has a domain of wireless coverage. An OBU is associated with one AP at a time, as long as it is in the router coverage domain. WMN allows vehicles (and OBUs) to move freely and associate themselves with different mesh routers. However, WMN is limited by the capabilities of the underlying wireless protocols. This implies that Wi-Fi-based WMN does not provide guarantees on maintaining communication sessions between an OBU and the WMN. For ITS applications, this calls for a mobility management scheme that maintains content delivery as vehicles travel through city streets.

3). To enable scalability of content delivery, the architecture distributes content over a group of content servers to improve system performance. We propose a hierarchical organization of content servers. We propose different schemes with the objective of balancing loads of distributing content among WMN AP and enhancing the throughput of content delivered to travelling vehicles. Distributing content delivery enhances the system scalability and reliability by avoiding a single point of failure. The schemes take advantage of the quasi-stationary nature of the WMN infrastructure. We describe a set of simulation experiments that characterize the performance of these schemes and compare it to that of standard IEEE 802.11 handoff process.

The paper is organized as follows: related work is described in Section II. Section III describes the proposed hierarchical and service-oriented architecture for content delivery, including mobility management and load-balancing aspects. This is followed by performance evaluation experiments and a set of concluding remarks.

II. RELATED WORK

In this section we review work related to service-oriented ITS content delivery and related components of wireless mesh networks, and mobility management protocols. One example is the Cabernet architecture [13] that delivers data to moving vehicles in and around a city using open 802.11 APs. The system reduces the mean connection time with APs and enhances network throughput over TCP. However, there's no guarantee for the load to be equally distributed over the available access points. In addition, the system depends on open APs, which might not be available in some areas. Scanning process still takes a considerable delay when associating with a new AP as the new channel may be any of the 11 channels used in IEEE 802.11. Another example is the infoshare architecture [14] that enables information sharing among moving vehicles. The application uses IEEE 802.11 for information transmission/ retrieval. A limitation of infoshare architecture is the focus on a road segment between two gateways; each gateway has a certain number of information pieces. It assumes that some vehicles managed to receive some pieces of information and it is required to share these pieces with other vehicles. The performance of this application depends on the number of vehicles on the road, as the number of vehicles increases, cached information increases and system response time decreases. As a third example [12], the authors proposed a service infrastructure built on top of Vehicular Ad-hoc Networks (VANETs) and uses an application layer protocol to consume services between vehicles. This protocol, however, depends on vehicle density, results indicate that response time and dropping rate increase as the gap between vehicles increase.

In our approach, we use wireless mesh networks to provide a reliable environment for content delivery. Current state-of-the-art in WMN research focuses mostly on studying and analyzing communications and networking aspects of WMN [1], [2], [5] with emphasis on using WMN as access networks using multi-hop routing techniques. WMN links exhibit variant quality over time. In addition, node mobility affects performance, guarantees, and end-to-end Quality of Service (QoS). The socket-based architecture fails to serve the anticipated WMN applications [6]. Research in delay-tolerant networks have suggested using a store-and-forward approach to networking where information is sent to an intermediate station where it is kept and sent at a later time to the final destination or to another intermediate station.

The effectiveness of real-world WMN for ITS applications is determined largely by its ability to reliably cover larger municipal areas for longer durations. However using wireless mesh networks in vehicular environment mandates mobility support. Vehicles are moving from one AP to another. It's necessary to minimize time needed by vehicle to re-associate with a new AP. In addition, the interrupted communication session should be maintained.

A prediction-based fast handoff approach was introduced in [7] where the APs were predicted in advance based on a predefined route. This approach assumes that mobility characteristics of a vehicle are known and hence the location and time of the handoff can be predicted. This renders this approach to be generally applicable for public transportation. Another approach proposed in [8] allows a vehicle to determine the APs using the current vehicle location and topology information available from a location server. This approach requires additional hardware devices to determine the current location of the vehicle such as GPS sensor.

For vehicles/nodes moving in a bounded area, selective scanning in combination with caching mechanism is proposed in [9] to reduce the scanning delay in IEEE 802.11 networks. Full scan is only needed at a first time vehicle associates with an AP, and then selective scanning is used to reduce the discovery time. Caching of AP MAC addresses is used for further improvements, In case of cache hit, the handoff delay is reduced to a minimum. However, a cache miss represents a problem for this approach which renders this approach not be suitable for ITS applications as the probability that a vehicle re-associates with a previous AP is very low.

The MobileIP protocol [4] is used as a typical solution for the session maintenance problem. Triangle problem is the main disadvantage for this approach [15]. Besides, using mobile IP in WMN may result in significant degradation in performance: A performance study, presented in [16], shows that as the number of hops increases from one to five, the handoff delay increases from 750 ms to 3.5 seconds. A possible solution for mobility management within WMN is proposed in [17], where, each mobile node is assigned a fixed IP address. The option field in IP packet header is used to store the current location of both sender and receiver. The disadvantage of this approach occurs when AP receives a packet in which the location of the receiver is unknown, in which case, the AP will have to broadcast a route request message to all APs and wait for a response. Another disadvantage of this approach is that it requires changes in the network layer of all mesh nodes and hence off-the-shelf devices have to be modified to be integrated in the network.

III. ITS CONTENT DELIVERY ARCHITECTURE

In this section, we describe the proposed architecture of ITS content delivery including hierarchical structure of the content servers, service-orientation aspects, mobility management mechanisms and load-balancing schemes.

A. Hierarchical Content Delivery

The proposed ITS content delivery uses network hierarchies to provide network scaling features. In hierarchical networks, a geographic area is divided into adjacent but distinct hexagonal clusters/cell. The size of each cell may differ based on population and traffic volumes. The segmentation of the road network into smaller domains distributes content delivery loads among many servers. APs communicate with vehicles travelling in their geographical cell in order to gather ITS information as well as to deliver ITS content and application data. Cells are then grouped together into domains managed by a (hierarchy level 1) domain manager. Domains can be grouped together, recursively, where a (hierarchy level n) level domain manger manages a number of (hierarchy level n-1) domain managers. This grouping continues until a rooted-hierarchy is built. The root server (either a single server or a server farm) maintains ITS content and is typically located at headquarters offices over the Internet.

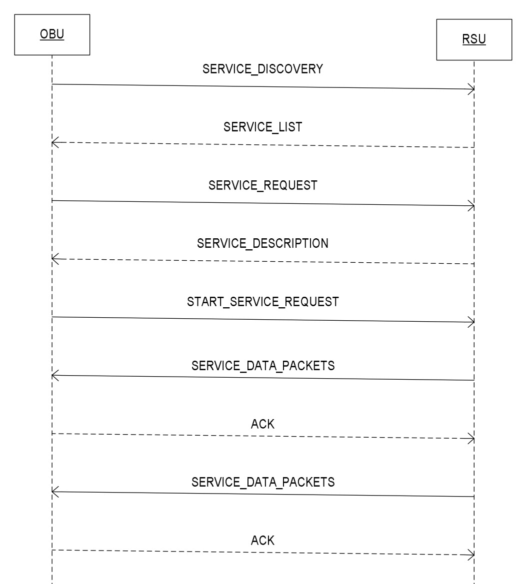

Fig. 2: The Messages exchanged between OBU and RSU

An example of a three levels hierarchical network structure is shown in Fig. 1 with 6 hexagonal cells. Within this architecture, a vehicle OBU communicates with the AP using Wi-Fi (or, in the future, other types of wireless communications). All APs are configured to run Optimized Link State Routing (OLSR) [10] OLSR enables AP to automatically configure the WMN and enables self-healing for the network in case of a failure of one or more AP. Different APs interact with each other using Wi-Fi to transfer information to and from a Wi-Fi gateway. The gateway AP receives/ forwards information using TCP/IP connections on the Internet where packets are rerouted to reach the surrogate and origin Servers.

The content delivery procedure begins as a travelling vehicle is in proximity with a road-side WMN AP. The OBU of the vehicle wirelessly "pairs" with this WMN AP. The OBU enters into a content discovery mode and queries the AP for available content. Assuming requested content is available, the OBU selects and consumes it. This selection is translated into a number of messages exchanged between the WMN AP and OBU that results in beginning the download of the file to the OBU. As the vehicle travels away from the AP, the wireless signal received becomes weaker and eventually the wireless connection with the AP is interrupted. As the vehicle continues to travel along the road, it becomes in range with another WMN AP. The vehicle requests the continuation of the interrupted service (e.g., continue downloading the same file) from the latter AP, assuming content is available at this AP as well. The process of the vehicle connecting to each AP on the road and requesting the continuation of the service continues until the service is completely consumed (e.g., the file is completely downloaded).

In case the requested content is not available at a WMN AP, the OBU request is forward up the CDN hierarchy to parent domain managers until the request reaches a domain manager that caches a copy of requested content. In the worst case scenario, an OBU scenario will travel up the CDN hierarchy to reach the root server. Based on this scenario, each surrogate server will maintain the following information, parent node address. Knowledge of the geographic cells it is managing, list of all services it maintains and the metadata associated with these services.

B. *Hierarchical Content Delivery*

To enable more efficient content delivery, we rely on the general concepts of service-orientation including: service description, discovery, and service maintenance while roaming. ITS content is considered as services that can be described, automatically discovered and consumed by vehicle/OBU. Figure 2 depicts the messages exchanged within the architecture to discover and consume services. The Extensible Markup Language (XML) is used to encode metadata describing each service. Parsing the list of available XML-based service descriptions available at a WMN AP, an OBU can determine the characteristics of the service it is looking for. For the OBU to be able to parse XML service description, an XML service description schema is defined and is known to all OBU's in the system. Defining common service description (or schemas) is necessary to ensure the ability of applications to automatically discover and consume services. In general, a service description consists of two required sections, namely ServiceHeader and ServiceContext. Each section has XML tags that correspond to service attributes. The ServiceHeader contains attributes that are mandatory for all services. Each service should be an instance of a specific type of service identified by the value of the ServiceType attribute. The ServiceID attribute's value associates a unique identifier to each instance of the service type. The ServiceName attribute uniquely identifies the service by a name that describes the service at an abstract level. The value of the ServiceStatus attribute indicates whether the service is available or not. In addition, there may be a textual ServiceDescription attribute. The ServiceContext section describes the properties of the service that are specific to each service. The ServiceData attribute provides information about the service type, size and date and time and validity of information. The ServiceProvider attribute provides information about the service provider. Within our network architecture, ServiceProvider (e.g., surrogate servers and WMN AP's) maintains content (or services) as well as a description file for each piece of content (service).

A second component required for service-orientation is service discovery which refers to the ability of an OBU to discover the services available at a WMN AP. Service discovery is typically carried over by exchanging messages between the OBU and AP. These messages include: Service_discovery, Service_list, Service_request, and Service_description. Figure 2 shows the sequence of interaction between an OBU and an AP to carry out service discovery. The OBU is presented with a list of services by the AP. The OBU parses these lists of XML service description headers and selects a specific service. Then the AP forwards a complete description of the requested service to the OBU. This completes the service discovery process. The OBU is now ready to start receiving data from the AP.

A third component required for service-oriented content delivery is mobility management and content delivery sessions maintenance as vehicle roams. We present the Service Mobility Management Protocol (SMMP) that enables continuous service consumption in spite of handoffs. Generally, within ITS applications, it is of high importance to reduce the handoff delay due to the higher speeds at which vehicles travel. Since the range of wireless coverage of AP is limited, handoff occurs frequently (every few seconds). For example, if the speed of a vehicle is 100 km/h and mesh routers are separated by 200 meters, it is expected that the handoff occurs every 5 seconds. This mandates the reduction of handoff delay.

Generally speaking, WMN AP can predict which other WMN AP to forward vehicle MAC addresses to. This is assuming vehicles are limited to travel along streets and highways. In addition, the quasi-stationary nature of WMNs enables the proposed content delivery network of implementing roaming triggers that enables WMN AP of predicting handoff events. Roaming triggers can be based on predefined provisioning policies pertaining to the link quality (RSSI levels) detected between the OBU and WMN AP. As RSSI levels go below a specific threshold value (a trigger), retransmissions of content data becomes more probable which results in reducing data transmission throughput.

It is noted that service-consumption sessions are performed at the service (application)-layers. That is, although the communication link is disconnected, the session itself can be resumed if the client rejoins the network before the session times out. This allows for seamless roaming regardless heterogeneities in communications layers protocols.

C. Fast Handoff mechanism

The handoff process in IEEE 802.11-based MAC Layer requires the mobile node (i.e., the OBU) to perform three main operations; scanning, authentication and association. Scanning takes the longest time among the three processes (over 90%) [9]. As the IEEE 802.11b standard uses about 11 channels for communication, the OBU has to scan all channels to find the one to use to communicate with the AP. Scanning can be done either in active or passive mode. In passive mode, APs periodically broadcast beacon frames to announce their presence. The mobile nodes listen for a certain period of time at every channel to receive the beacon frames. Using the information from these beacon frames, the mobile node chooses which AP to be associated with. In active mode, the mobile node broadcasts a probe request and waits for a response from the AP. If it doesn't receive a response for a minChannelTime period of time then the channel is considered idle. If at least one response is received, it will use this channel for a maxChannelTime, before moving to the next channel. The process is repeated for all the 11 channels.

The node uses all the information from scanning to determine the best AP that has the maximum signal strength. After that the node proceeds to the next process of authentication and then association. In general this process is considered too long to allow for service roaming within ITS applications. It has been shown in [9] that selective scanning with a pre-known MAC addresses reduces the total handoff latency to about 3ms.

In order to reduce handoff time, a fast handoff mechanism is implemented. This mechanism relies on the quasi-stationary nature of the WMN infrastructure. Through the operations of OLSR neighbour discovery, each WMN AP's knows the MAC address of its one-hop neighbour APs. Now, when the vehicle joins WMN for the first time it performs full scan for all channels in accordance to the standard IEEE 802.11 process. Once the vehicle is associated with a mesh router, the router broadcasts the MAC address of all its one-hop APs to the vehicle using a Neighbor Discovery message. The vehicle caches these MAC addresses. Now as the vehicle travels through the street/ highway and the vehicle is handed off, the vehicle will use the list of addresses maintained in its cache to scan for APs. If none of MAC entries cached is available (due to failure in the neighbouring AP for example) then the standard IEEE 802.11 scan is performed. Once a vehicle is able to perform scanning, the authorization and association processes are performed. The roaming process is shown in Fig. 3.

D. Load-Balancing schemes

To enhance the throughput of data delivered out of each AP while maintaining load balance, we propose selective-association schemes. These schemes divide vehicles into vehicle groups. Vehicles from one group follow the same pattern of associating with WMN APs. When vehicles join the WMN (i.e., associate with the first AP in the WMN; AP1), they will be assigned to a vehicle group and this determines the pattern of AP association. Pattern selection is made based on a number of factors such as vehicle speeds, the distance between WMN APs and the mobility management protocols used. Although these schemes require AP pre-configuration, they distribute the content delivery load over available APs and allow vehicles to stay a considerable amount of time with each AP. The results show that using these mechanisms results in a significant enhancement in performance compared to the standard IEEE 802.11 association mechanism. We investigate 3 different selective-association schemes:

- One-hop caching scheme: where the vehicles forms only one group and all the vehicles associates with AP that are one-hop apart. That is, each vehicle associates with AP in sequence For example, all the vehicles will associate with AP1, AP2, AP3, AP4, AP5 … and so on.

- Two-hop caching scheme: where the vehicles are divided into two groups. With this scheme, each vehicle associates with one AP and skips the following AP.

- Three-hop caching scheme: where the vehicles are divided into three groups. With this scheme, each vehicle associates with one AP and skips the following two AP. Again, as all vehicles join the network through AP1. Vehicles of the first group will associate with AP2, AP5, AP8 … etc and vehicles of the second group will associate with AP3, AP6, AP9 … etc while vehicles of the third group will associate with AP4, AP7, AP10… etc.

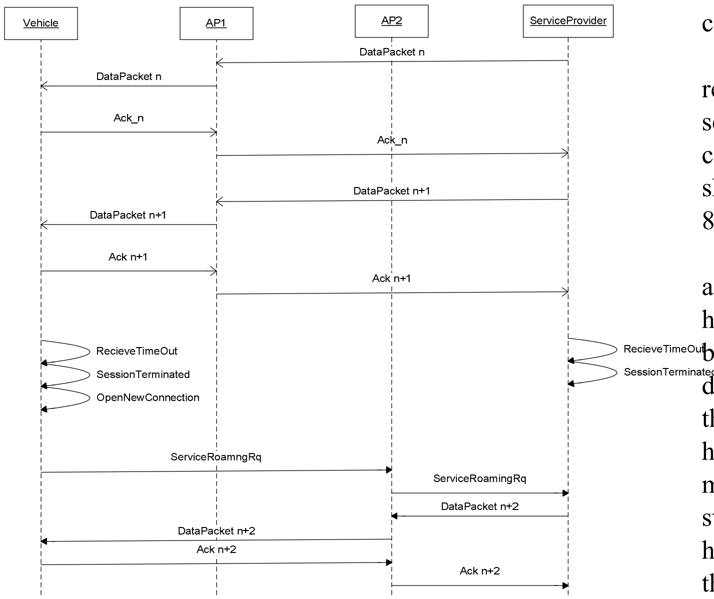

Fig. 3: Service roaming sequence diagram

IV. PERFORMANCE EVALUATION

To evaluate the performance of the proposed architecture, we used the open source discrete event simulator OMNET++ v3.3 (www.omnetpp.org/). The simulator is used with INET-20061020 framework that contains models for TCP/IP and IEEE 802.11b, in addition to pre-defined node mobility patterns such as linear, circular and random mobility. We modified the Wireless Host and Wireless AP modules of the INET framework to support service-orientation, SMMP and Mobile IP [4].

A simulation for 38 vehicles with 44 meters inner distance travelling on a highway is developed. The vehicles move horizontally along a straight line (the highway). Both vehicles and mesh routers are uniformly distributed along the motion path of the vehicle. Values of 2ms and 27ms were used for MinChannelTime and MaxChannelTime respectively [11]. We ran each simulation experiment for 80 seconds with vehicle speeds ranging from 0 to 100 km/h. Each vehicle requests for a 20 Mb service to be transmitted through the network. We assume that none of the routers will fail during the experiment and that all APs have the same coverage ranges within one experiment. Another assumption is that the co-channel interference is at minimum.

To evaluate the performance of SMPP (with MAC address caching), we conducted experiments to compare it to both standard IEEE 802.11 handoff protocols (with active scanning) and the Mobile IP protocol (we modified the IP modules of the INET framework). The performance of SMMP is evaluated using the following metrics: 1) time spent to handoff a vehicle; 2) data throughput as received by a vehicle; 3) effect of vehicle speed on the data bytes received; and 4) effect of the mobility of two vehicles on the throughput of the content they received

Fig. 4 shows the throughput of downloaded data packets as received by the vehicle. We have run the experiment for 60 seconds with vehicle speed of 100 Km/h. Data throughput is calculated every 0.1 sec. The figure shows that SMPP has a shorter handoff time when compared to the standard IEEE 802.11 and Mobile IP mobility management protocols.

In the figure 4, 6 cycles of the vehicles going through associating with an AP, downloading data and then being handed off to another AP. The levels of throughput that occur between 3-9, 12-19 and 22-28 seconds indicate vehicle is downloading data from different WMN APs. The drop in data throughput that occurs at 9, 20 and 30 seconds indicates handoff operations. Although the figure shows that the maximum throughput of both SMMP and IEEE 802.11 standard methods are approximately equal, SMMP has faster handoff than IEEE 802.11 standard method. Figure 5 shows the effect of the speed the vehicle is travelling with on the throughput received at the vehicle. As the speed increases, the number of received bytes decreases. In other words, as the number of handoffs increases, the time wasted during handoffs (without downloading data) increases. This is obvious in the figure by the negative slope the three curves have. The figure also shows that since SMMP has shorter handoff times, more time is spent downloading data, and hence more throughput is achieved with SMMP that with IEEE standard method and Mobile IP (which has the lowest throughput amongst all protocols).

In addition, we study the effect of different association schemes on the performance of content delivery through the following metrics: 1) the amount of data transmitted from each AP which represents the load of ITS content delivery; and 2) the throughput of data received at vehicles. We study these metrics as the following parameters change: 1) the speed of vehicles, that varies between 0 - 100 Km/hour; and 2) the inter-AP distance varied between 25 and 300 meters while transmission power and coverage range remains constant.

We study the performance of content delivery as vehicle travel at maximum speeds of 100 Km/hour. This results in the largest number of handoffs possible as a new vehicle is at closest distance to an AP every 1.6 sec. Figure 6 compares the average throughput received at all 80 vehicles (shown on the vertical axis) as the inter-AP distance (horizontal axis) changes for the four handoff strategies: namely, the standard IEEE 802.11 active scanning, one-hop, two-hops and three-hops MAC-Address caching. As shown in the figure, caching schemes has much better throughput when compared to the standard IEEE scheme specifically at shorter inter-AP distances (between 50 -175 m). As the inter-AP distance gets shorter (e.g., 25 m), the using of one-hop caching results in very rapid switching between APs as the distance is very short and hence the average throughput at vehicles decreases.

Fig. 7 and Fig. 8 compare the total transmitted bytes

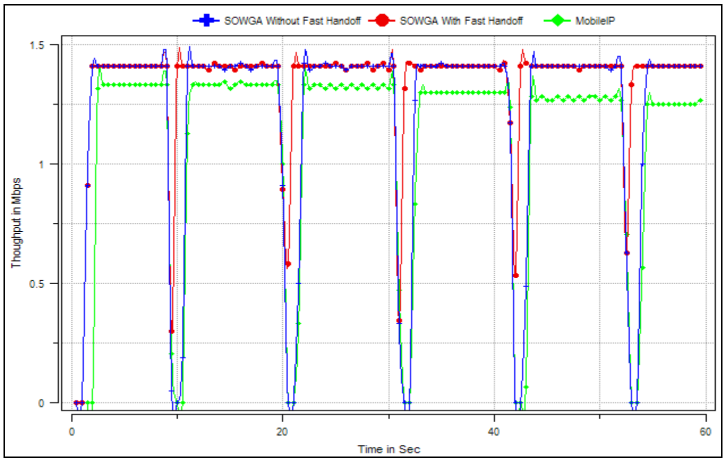

Fig. 4: Data Packets Throughput seen at the vehicle moving with speed 100 km/h

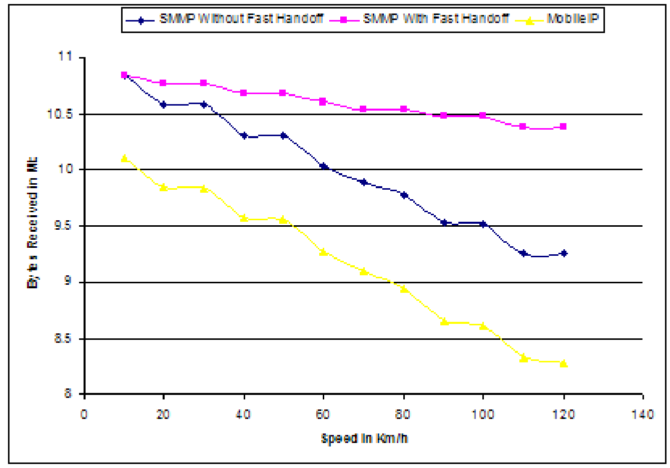

Fig. 5: Effect of the speed on the received bytes at the vehicle

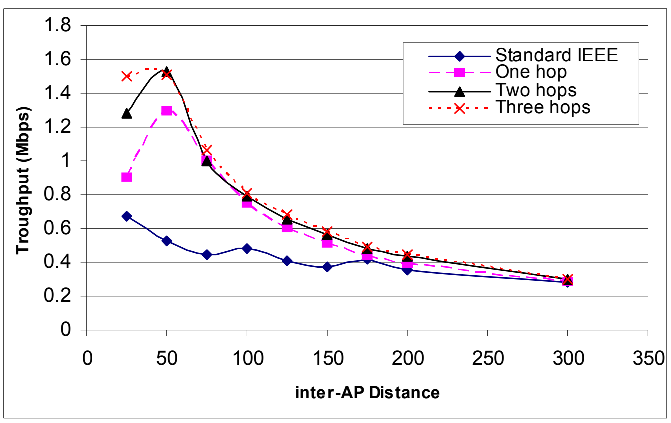

Fig. 6: The effect of inter-AP distance on the average data throughput for the different mobility management schemes.

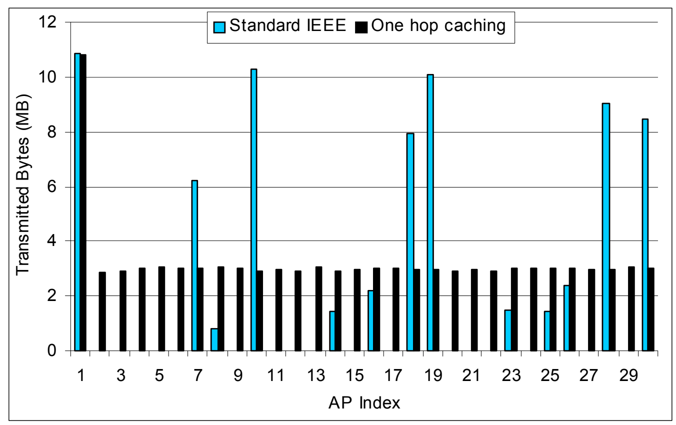

Fig. 7: Total number of transmitted bytes at each AP with 25 m inter-AP distance and 100 km/h vehicle speed

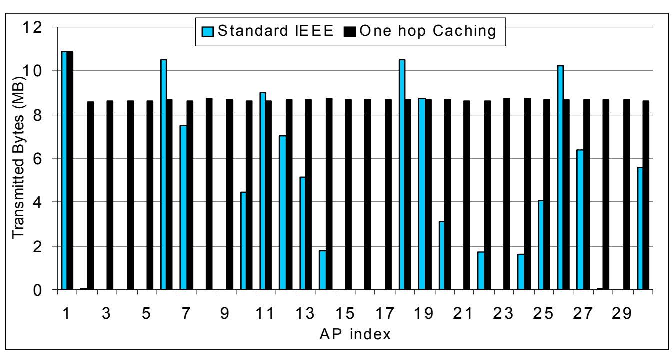

Fig. 8: Total number of transmitted bytes at each AP with 50 m inter-AP distance and 100km/h vehicle speed

(vertical access) out of each AP (AP index shown on horizontal axis) for the one-hop and IEEE active scanning schemes at an inter-AP distance of 25, and 50 meters, respectively for vehicles travelling at 100 km/h. It is clear from the figure that IEEE active scanning results in more sporadic associations with AP which, in turn, results in uneven content distribution loads among all APs considered. For example, all vehicles in the simulation experiments associate with AP1 as they join WMN. For smaller inter-AP distances (e.g., 50 meters in Fig. 8), using the IEEE standard active scanning scheme, all vehicles are not able to associate with AP 2, 3, 4 and 5, which means that these 4 APs do not distribute content. Other APs such as 14, 22 and 24 participate in content delivery with a minimal amount of data.

Using IEEE active scanning, vehicles try to associate with nearest AP (strongest signal). As the distance gets shorter, and due to the long time of scanning, the vehicle may skip associating with some APs. The other handoff management strategy, one-hop MAC address caching, results in more balanced content distribution loads among all AP's considered because all vehicles have to associate with AP1, then with AP2, then with AP3 and so on. The consecutive caching of AP MAC address at each vehicle ensures that each vehicle associates with all AP. This ensures that all AP are involved in content distribution. Another conclusion from the figures is that as the inter-AP distance increases, the throughput delivered out of each AP increases. This is because vehicles will associate with AP for longer times.

V. CONCLUSIONS

This paper presented a service-oriented ITS content delivery architecture using wireless municipal mesh networks. The architecture uses the WMN APs to deliver content to moving vehicles along city streets and highways. WMN receive this content from surrogate and origin servers. The architecture considers content as a service and uses XML metadata to describe that content. Vehicles automatically discover and consumes (e.g., download) contents based on content description. We described a protocol that is used by vehicles to discover and consume content available at WMN AP. We took advantage of the quasi-stationary nature of WMN AP to enhance mobility management and load balance content delivery workloads among AP. We realized that using MAC address caching schemes results in balancing the loads of distributing ITS content to vehicles as compared to the IEEE standard scheme. We introduced a service-oriented mobility management protocol to overcome intermittent connectivity issues in content delivery while cars are travelling along the road network. The proposed schemes build on the standard IEEE 802.11 handoff schemes The protocol provide vehicles with MAC address of the WMN AP the vehicle is expected to associate with in the future. Vehicles cache these MAC addresses and use them to discover APs. This significantly reduces the time taken to associate with an AP which reduces handoff time and consequently increases the data throughput delivered to vehicles. In addition, we also introduced association mechanisms to load-balance content delivery workloads among WMN AP. The MAC address caching schemes control vehicle association to WMN as opposed to the IEEE scheme that leaves it up with no control.

We studied the performance of the mobility management protocol and compared it to the performance of the standard IEEE 802.11 handoff mechanisms and Mobile IP. We found out that the proposed protocol has shorter handoff times than both other methodologies (with Mobile IP having the longest handoff times). In general, shorter handoff times indicate more times available for downloading data which results in higher data throughputs received at vehicles. We have also studied the performance of the proposed load balancing schemes at different AP separation distances. We found out that the two-hop and three-hop MAC caching schemes have better throughput for medium distance (between 25 and 100 meters) than the one-hop caching scheme. The three MAC address caching mechanisms have a bit of advantage on IEEE standard handoff scheme at longer inter-AP distances (200 - 300 meters).

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