IEEE 2012 GLOBECOM
GLOBAL COMMUNICATIONS CONFERENCE,
EXHIBITION & INDUSTRY FORUM

Issue 5
Friday, 7 December 2012

Conference Addresses

IEEE GLOBECOM 2012 Executive Chair Pierre Perra opened Thursday morning's schedule by reminding the forum about the day's numerous events including the drawing of prizes and the afternoon's Lightning Talk session highlighted by short five minute talks presented by conference attendees on the technical topics of their choice.

Immediately following these introductions was the keynote presentation of Stephen B. Alexander, Senior Vice President and Chief Technology Officer of Ciena, who spoke about "The Performance-on-Demand Application Ecosystem: The Next Phase of Telecom Infrastructure." According to Alexander, "networks matter more today than over the past 20 years due to the overwhelming demand for capacity by providers." As a result, the very nature of connectivity has changed requiring its reconfiguration into a "performance-on-demand application ecosystem" that connects people operating through 500,000 locations and 50 billion machines.

Alexander then continued by stating that the "biggest change in the industry landscape in my lifetime is the delivery of over-the top services" that have generated the need for new emerging ecosystems built sensibly through the combination of connect, compute and store capabilities working together to create platform infrastructures." In the past, he added, "traffic patterns could be estimated," but real change occurs when you start connecting people through machines that can be extremely unpredictable.

In addition, he also highlighted the differing nature of today's business model that demands for network infrastructures "that must get 100 times bigger, but can't cost 10 times more or use 10 times more energy." However, he did note that this is "the first time that the industry has had a global ubiquitous standard -- the Ethernet -- that has created convergence," while citing the benefits of coherent optical communications and its ability to break down barriers, change behaviors and make propagation independent of fiber.

Going forward, Alexander then discussed the industry's "motivation for change," which is driven by "centralized and virtualized" network functions that turn central offices into content centers operating fully-programmable, seamlessly integrated computing and storage resources that offer great scale at low cost. This includes the ability to apply software-enabling capabilities that rapidly and intelligently support their cross-platform management and "establish the global virtual fabric for models that can be expanded through the world."

During the morning's second keynote, Hossein Eslambolchi, Chairman & CEO of 2020 Venture Partners, addressed "The Power of Technology to Transform the Future" through the evolution of the network, cloud and future services. In his presentation, Eslambolchi spoke at length about the technology trends that are driving the network's massive transformation as well as the opportunities for next-decade services that "will impact every person and business in one seamless, virtual world." Eslambolchi approached this list by noting the necessity for fully-integrated architectures since the "network of today" and the "Internet was not designed to support the latest requirements" and that there is a "massively critical" need for security, which has previously been administered through band-aid solutions.

In the new world, he also stated that e-collaboration and mobility will dominate the workplace, "wireless access will be common" with personal device convergence and remote intelligence sensors everywhere and "a massive growth in data business intelligence units will provide better optimization across entire infrastructures." In addition, Eslambolchi predicted that 50 percent of all workloads will be processed in the cloud by 2014.

However, his speech also presented several challenges. According to him, there is a looming bandwidth gap that will result from the exploding demand for mobile data. Subsequently, this will lead to a "spectrum-multiplying" solution that will ultimately solve the crunch and inevitably "enable optimal data usage with richer multimedia experiences."

As for Dr. Eslambolchi's recommendations to service providers, he posed several "Do or Die" propositions including the necessity to create elasticity that accommodates new traffic patterns as well as software-driven, converged services that offer personalized customization. After offering his vision of 2015 that entailed the dominance of IPv6 and the introduction of speech to speech translation devices and hi-definition interactive video, he also stated that 2025 will likely spell the end of broadcast TV since the same programming will be available over the Internet. In conclusion, Dr. Eslambolchi ended his talk by asking questions like:

- Should the network be the basis for Internet innovation or should the Internet be the basis of network innovation?
- Should the network control security or should security control the network?
- Should networks be the center of the universe or should applications rule the center?

TABLE OF CONTENTS

EVENTS OF THE DAY

08:00 – 18:00
WORKSHOPS

08:00 – 15:20:
W13: Emerging Technologies for Smart Devices (ETSD)
/ North Exhibit Hall B

08:00 – 17:00:
W17: Flexible Optical Networks (FON)
/ North Exhibit Hall F

08:25 – 17:20:
W14: Management and Security Technologies for Cloud Computing (ManSec-CC) / North Exhibit Hall C

08:30 – 16:30:
W15: Rural Communications (RuralComm)
/ North Exhibit Hall D

08:30 – 17:00:
W20: Wireless Networking and Control for Unmanned Autonomous Vehicles (Wi-UAV) / North Exhibit Hall I

08:30 – 17:30:
W22: Quality of Experience for Multimedia Communications (QoEMC) / North Exhibit Hall J

08:30 – 18:00:
W18: Machine-to-Machine Communications (IWM2M)
/ North Exhibit Hall G

08:45 – 15:30:
W16: Green Internet of Things (G-IoT) / North Exhibit Hall E

09:00 – 12:00:
W12: Ad Hoc Networking with MIMO and Cognitive Radio (MIMOCR) / North Exhibit Hall A

09:00 – 17:30:
W19: Open NGN and IMS Testbeds (ONIT) / North Exhibit Hall H

09:00 – 12:00
TUTORIALS
T7: Interference Alignment / Monorail
T9: Opportunistic Communication / Magic Ballroom 1/4

12:00 – 14:00
LUNCH (Workshop and Tutorials (AM) Only) / Center Ballroom

14:00 – 17:00
TUTORIALS
T10: 4G LTE Wireless Networks / Monorail
T11: Joint PHY-MAC Design / Castle
T12: Cooperative Spectrum Sensing / Magic Kingdom Ballroom 1/4

PROGRAM UPDATES

The following are updates to the program guide found in your badge holder. These updates appear in the online final program.

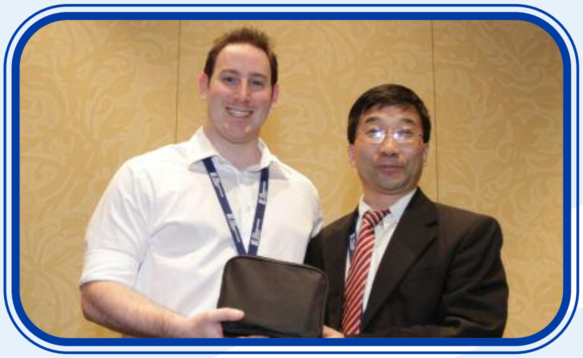
Friday, 7 December 2012

T9: Opportunistic Communication
from 09:00 – 12:00 will now be held in Magic Kingdom Ballroom 1/4.

T12: Cooperative Spectrum Sensing
from 14:00 – 17:00 will now be held in Magic Kingdom Ballroom 1/4.

EXHIBIT HALL

From the Exhibit Floor…



Wednesday Industry Forums Highlighted New Educational Learning Methods & Utility Pricing Schemes

The IEEE GLOBECOM 2012 Industry Forum schedule continued on Wednesday afternoon with two sessions dedicated to enhanced wireless learning methods and smarter pricing modeling for providers who are confronted with the ongoing challenges of rapidly rising traffic rates that are growing faster than revenues streams.

David Michelson, the director of education at IEEE ComSoc, opened today's Education Forum by highlighting the society's mission to formulate educational strategies, appoint working group members, promote telecommunications as a distinct engineering discipline at U.S. universities and develop best practices for conference and web-based tutorials. Following these introductions, the session's expert panel representing Ettus Research, National Instrument, the University of Texas, Austin, Rockwell Collins and RWTH Aachen University discussed the fundamentals of "How Software Defined Radio Will Revolutionize Lab-based Communication Courses." This included an explanation of The Universal Software Radio Peripheral (USRP) and its use as a wireless communications research and real-world radio system prototyping tool that has been proven to enhance hands-on classroom experiences and help prepare students for careers in wireless communications.

Matt Ettus, founder & president of Ettus Research initiated the talk by stating that "you have to feel and touch radio and be exposed to the nitty, gritty details to truly understand its realities. Software radio fills the need for education to provide a smooth transition from modeling to reality, while offering a perfect mode of experimentation."

Afterwards, Erik Luther of National Instrument extended the reasoning by speaking about the benefits of "Do Engineering: The Value of Hands on Engineering" generated through the "creation of emotional experiences that enable the entry into discovery." He then cited the success stories of several major colleges including Stanford University, which developed programs empowering students to "apply theory as it fits into a bigger system," shorten the learning cycles at new jobs and turn classroom failures performed in safe settings into the ability to overcome obstacles with confidence in industrial environments.

Held simultaneously was also the Industry Forum on Smart Data Pricing chaired by Professor Mung Chiang of Princeton University. During the proceedings, Shyam Parekh of AT&T Labs offered his comments on the drastic choices currently confronting Internet Service Providers (ISPs) as they attempt to increase flat profits in an industry currently besieged by the tremendous demand and provision of mobile broadband data traffic. According to Parekh, the implementation of the right controls and smart pricing traffics will not only increase revenues and lower CAPEX/OPEX, but also higher QoS, lower blocking and abandonment, eliminate selfish users, create new opportunities for QoS pricing and produce new demands based on incentives.

Immediately afterwards, Matthew Andrews of Alcatel-Lucent then reviewed the options posed by shared data, toll-free data, comes with data, real-time service aware, personalized bundle, dynamic time congestion, QoS-based and M2M pricing alternatives. All of which, he said must be determined through a combination of the provider's utility, analytical research designed to discover the user's response to plans and the ability to implement complex pricing scales at scale.

IEEE GLOBECOM 2012 Annual Banquet Provided Night of Fine Dining & Entertainment to Hundred of Participants

The IEEE GLOBECOM Annual Banquet Dinner held Wednesday evening in the Grand Ballroom of the Fantasy Tower at the Disneyland Hotel included the attendance of hundreds of conference participants, organizers and honored guests, who wined, dined and mingled as a steady stream of entertainment performed on-stage.

During the event, Executive Chair Pierre Perra initiated the night's proceedings by welcoming everyone and thanking exhibitors, the IEEE Organizing Committee, IEEE ComSoc staff and patrons such as Ciena and Samsung for helping to make this year's IEEE GLOBECOM so successful and memorable. Also introduced was the IEEE GLOBECOM 2012 executive Committee, who were greeted with a loud round of applause from the full room. Afterwards, the entire audience was treated to the gymnastic and musical talents of the Azusa Pacific University Marching Band and Color Guard as well as the brief comments of IEEE ComSoc President Vijay Bhargava, who posed the question "When was Walt Disney born?" The answer, 5 December, the evening's date.

Later at the banquet, Executive Chair Perra coordinated the traditional passing of the globe to Lajos Hanzó, the Executive Chair of IEEE International Conference on Communications (ICC) to be held 9 – 13 June 2013 in Budapest, Hungary. Executive Chair Hanzó continued by inviting all to attend the upcoming five-day premier, international event and take advantage of the opportunity to experience the conference's "exquisite cultural and scientific program." Further welcomes were extended by General Chair Christopher Mattheisen through the showing of a brief video detailing the conference theme of "Bridging the Broadband Divide" as well as the many amenities offered at this European cultural and industrial center. IEEE GLOBECOM 2013 General Chair Branko Bjelajac then joined Executive Chair Perra on stage to speak about next year's event in Atlanta. This invitation was supported by another on-stage video focusing on the city's energy, cultural treasures, spectacular shops and entertainment.

Shortly afterwards, the night concluded with the keynote presentation of Steven Rosenbaum, who was introduced by Executive Chair Perra as an American TV producer and filmmaker as well as the creator of the "9/11 Memorial: Past, Present & Future," among his many credits. Rosenbaum started his address by noting that "the room had the potential to make really important changes around this thing called the 'Digital Overload.' That's because the question we're all facing is the line between being plugged-in and overloaded. Nothing good comes from emails after 10:00 p.m. It's always generally bad news. But, many of us are driven to check emails first thing in the morning and the evening… It's making us all crazy."

Rosenbaum proceeded to cite several examples including the fact that 294 billion emails are sent daily and it would take nearly eight years to watch the 864,000 hours of video uploaded to You Tube in one day. As a result, 78 percent of people check email relentlessly and 34 percent admit to sleeping less in an attempt to stay above of the information crush.

As a result, Rosenbaum challenged the audience, which was "probably composed of the smartest group of people" he ever addressed, "to solve the problem by making the digital world simpler." According to Rosenbaum, "curation, not content, is king" and curators can perform several basic tasks to reduce the clutter and create clarity from this noisy world. Among them were the bundling and distribution of digital collections rather single items, the provision of a voice with tone to material and the re-ordering of content to make sure it offers the right mix of sources. He also ended the night by reminding everyone that "active listening is more powerful than speaking" and challenging us all "to invite the active participation of others."

Thursday Executive Forum on IT Transformation Discussed New World Network Infrastructures

The Executive Forum agenda at IEEE GLOBECOM 2012 continued on Thursday morning with the session on "IT Transformation: Clouds, Security, Mobility and Computing" exploring the challenges and opportunities confronting the transformation of today's IT and network infrastructures, which are currently being driven by the introduction and development of the latest cloud computing, virtualization, security, mobility and business social networking applications and services.

Flavio Bonomi of Cisco Systems began the forum by discussing "Computing and Communication in the Age of the Internet of Everything." This included highlighting the evolution of communications and applications on the web as the industry begins introducing the next wave of scalable and efficient cloud-based infrastructures and architectures needed to cost-effectively connect millions of devices. Included in this address was a review of the evolution of IPnets and Internet of Things (IoT) computerization that will in short-term provide the general functionality needed to create smart cities and connect vehicles through a common IoT platform.

As an example, Bonomi then cited the activities that are now underway to automate parking through the edge computer coordination of parking spot sensor data and traveler online requests. For this to happen in addition to other initiatives such as the development of highway multi-hop communications, he said, wireless connectivity strategies must be adopted that directly contradict today's models and exploit the use of smaller cells, locality and the simultaneous coordination of heterogeneous networks.

Following this presentation, Kaushik Arunagiri of EMC spoke about his company's vision of the cloud and the support of devices anytime, anywhere that will be facilitated through the implementation of new consumption and delivery models operating disruptive technologies and software-defined data centers. Next, Steve Alexander of Ciena, continued the discussion from the keynote he presented earlier that morning on "Performance-on-Demand Cloud Backbones." Amazed, he began by citing the findings of a recent study that said 51 percent of people believe weather can affect cloud computing. Afterwards, he spoke of servicing the information distribution needs of institutions like schools as well as single individuals through the secure cloud infrastructures utilizing nested layers and including data centers operating without walls.

As the session's final speaker, Mahbubul Alam of Cisco addressed the "forces" that are currently changing our world. First, he mentioned the growth of a new generation of people that use social networking more than email to communicate with friends, family and business colleagues. As a result, Alam believes that social networks will evolve with rich voice and video communications capabilities to challenge the usage of other, presently more popular platforms. Second and third, consumers are now driving the innovation cycle and even demonstrating the power to battle corporations through social media. For instance, he cited the efforts of the 22-year-old in Washington, who raised 300,000 petition signatures online causing Bank of America to rethink the institution of monthly charge card fees.

And finally, Alam described the rise of the "Internet of Everything" that will bring data, people and processes together in environments offering virtually endless opportunities. With this came his recommendations for success in this new world. They included "making change part of your daily life and working culture, constant experimentation and always leveraging what's available."

First-ever Lightning Talks Session Generated Nearly 20 Technical Presentations in Rapid-Fire Succession

The IEEE GLOBECOM Industry and Executive Forum schedule ended on Thursday afternoon with nearly 20 individuals participating in the conference's "Lightning Talks" session that provided each individual the ability to address their choice of technical topics. Moderating the "new experimental" event was Leonard Reder of JPL, who introduced the succession of speakers throughout the forum and kept the activities moving with tight five-minute time limitations.

First up was Francisco Moreno of BEECube, who offered the presentation "So Many Users, So Many Opportunities, So Little Spectrum, So Little Time." This began by referencing the data explosion and the ongoing convergence of the wireless mobile world with E-commerce that has currently produced more than one billion global smartphone users as well as $1 billion in sales on Black Friday within the United States and $4 billion in China on 11 November 2011. Following these comments, Moreno then spoke about the engineering challenges confronting an "all digital world" and the need to shorten design cycles that take all-programmable platforms from lab to the field in record times.

Bijan Golkar of the University of Toronto spoke next on "Autonomous Infrastructure Cellular Networks" and the utilization of smaller cells and a wide range of base stations deployed according to network traffic patterns. He was then immediately followed by presentations on social networks communicating over national language interfaces, "Additive Inverse Gaussian Noise Channels" and a talk highlighting the state of rural South African villages that are not only unconnected but represent the needs of nearly two billion people worldwide, who live "unequal" lives without the benefit of affordable, sustainable services.

In rapid succession, the ensuing presentations then dealt with topics such as "Wireless Software-Defined Networking: The Other Part of the SDN Equation," "Application Delivery Using SDN," "Ranplan Wireless Net Design," "Delay & Disruption Tolerant Networking," "Meshed Tree Algorithms," "Heterogeneous Cellular Networks," "QoE-aware LTE Scheduling Algorithms for Multiple Applications," "Collaborative Peer-to-Peer Systems," "Approximate Services in the Internet of Things" and "A Simple Counterexample for the Linearization Technique in Optimization."

After a brief orientation on the SARACEN (Socially Aware, collaboRative, scAlable Coding mEdia distribution) research initiative and its results of their research on P2P based media delivery of socially aware content, all session attendees were then invited to upload a film about IEEE GLOBECOM to the Saracen platform for a chance to win one of several prizes.

In conclusion, IEEE GLOECOM 2012 Industry Forum & Exhibition Chair Narisa Chu spent her five minutes in the session extolling the "brilliant and vibrant" nature of all of this year's presentations that included 34 sessions and keynotes as well as 12 tutorials produced through the combined efforts of 94 panelists, 34 chairs and 25 committee members.

MANY THANKS!

The IEEE GLOBECOM 2012 Organizing Committee would like to thank the 2,000+ registrants, volunteers, speakers, patrons and exhibitors for attending and supporting IEEE GLOBECOM 2012!

The next annual conference will be held 9 - 13 December 2013 in Atlanta, Georgia at the Hilton Hotel, in the heart of downtown's finest eating and tourism establishments. IEEE GLOBECOM 2013 will offer cutting edge communications technology symposia, forums, panel discussions, tutorials, workshops, industry exhibits and renowned industry CEOs & CTOs in panel sessions and keynote speeches. And be sure to schedule some time for yourself and your loved ones to experience many of the nearby family-friendly attractions, such as the largest indoor aquarium in the US, numerous museums for art, history, and science (and Coca Cola, of course!), as well as one of the finest restaurant scenes in North America.

For more information, including presentation submission guidelines, visit www.ieee-globecom.org/2013.

We look forward to seeing all of you at
IEEE GLOBECOME 2013!

IEEE GLOBECOM 2012
BEST PAPERS

On the following pages, the 2 of 15 best papers featured are from the Symposium on Ad Hoc and Sensor Networking.

FCM: Frequency Domain Cooperative Sensing and Multi-channel Contention for CRAHNs

Lu Wang
(Hong Kong University of Science and Technology, Hong Kong)
Kaishun Wu
(HKUST / Sun Yat-sen University, Hong Kong)
Jiang Xiao, **Mounir Hamdi**
(Hong Kong University of Science and Technology, Hong Kong)

A Distributed Infrastructure-Based Congestion Avoidance Protocol for Vehicular Ad Hoc Networks

Maram Bani Younes
(University of Ottawa, Canada)
Graciela Roman Alonso
(Universidad Autonoma Metropolitana-Izt, Mexico)
Azzedine Boukerche
(University of Ottawa, Canada)

FCM: Frequency Domain Cooperative Sensing and Multi-channel Contention for CRAHNs

Lu Wang*, Kaishun Wu*†, Jiang Xiao*, and Mounir Hamdi*

*Department of Computer Science and Engineering, Hong Kong University of Science and Technology
†National Engineering Research Center of Digital Life, School of Physics and Engineering, Sun Yat-sen University

Abstract—**Radio spectrum resource is shown to be significantly underutilized with fixed spectrum assignment policy. As a promising solution, cognitive radio allows unlicensed users to opportunistically access the spectrum not used by the licensed users. Cooperative sensing is further exploited to improve the sensing performance of unlicensed users by leveraging spatial diversity. However, cooperation gain can be compromised dramatically with cooperation overhead. Furthermore, when sensing decisions are made, contention on spectrum access also becomes an overhead, especially in the distributed networks. Motivated by this, we propose a novel MAC design, termed Frequency domain Cooperative sensing and Multi-channel contention (FCM). FCM moves cooperative sensing and multi-channel contention from time domain into frequency domain. Thus, the control overhead caused by cooperation and contention can be significantly reduced, without reducing the sensing and access performance. Extensive simulation results show that FCM can effectively reduce the control overhead, and improve the average throughput by 220% over Traditional Cooperative MAC for CRAHNs.**

I. INTRODUCTION

With the rapid growth of wireless communications and high demand on the deployment of new wireless services, the unlicensed bands, most in the 900MHz and the 2.4GHz, are getting more and more congested. Meanwhile, several licensed bands are shown to be extremely underutilized, such as TV broadcast frequencies below 700MHz [**?**]. Cognitive radio (CR) technology has recently been receiving significant research interest both from academia and industry, due to the poor spectrum utilization of fixed spectrum assignment policy enforced today. CR is envisaged to solve this critical spectrum inefficiency problem by enabling the access of the intermittent periods of vacant spectrum in the licensed band for the CR users, without affecting the licensed or primary users (PUs).

However, the design of CR networks imposes unique challenges due to the high fluctuation in the vacant spectrum and the opportunistic access among CR users. The first challenge is to accurately identify the available spectrum in real-time through spectrum sensing, while vacate the spectrum once the PU is detected. This sensing accuracy is compromised with many factors, such as multi-path fading and shadowing [1]. Recently, cooperative spectrum sensing has shown its superiority to improve the sensing accuracy by exploiting spatial diversity. After exchanging sensing information among spatially located CR users, each of them makes a combined decision, which can be more accurate than individual ones. However, cooperation overhead increases dramatically and comprises the sensing performance, especially in distributed networks. The second challenge is to share the available spectrum among different CR users once the sensing decisions have been made. As the available spectrum and node density increases, coordination overhead and transmission delay raise up accordingly, resulting in a significant performance degradation. These challenges necessitate efficient designs that can simultaneously address extensive problems in CR networks.

In order to solve the above-mentioned challenges and minimize the overhead of cooperation and contention for CR networks, we need to design a cost-effective MAC protocol, which consumes fewer resources on control transmission, and meanwhile ensures accurate and real-time spectrum information for data transmission. Recently, some works leverage OFDM (Orthogonal Frequency Division Multiplexing) modulation to move the contention from time domain into frequency domain, in order to improve the efficiency of 802.11 MAC [3]. Motivated by the researches using frequency domain for channel contention, we propose a novel MAC protocol for CR Ad Hoc Networks (CRAHNs), termed FCM (Frequency domain Cooperative sensing and Multi-channel contention). FCM combines both cooperative sensing and multi-channel contention in frequency domain. Specifically, we allow CR users to exchange and share their sensing information in a portion of OFDM subcarriers, and meanwhile contend for spectrum access in the other portion of subcarriers to construct an access order. With the available spectrum and access order at hand, CR users can undertake data transmission simultaneously in different available spectrum. Since decision sharing and multi-channel contention can be finished in the same short period, the coordination overhead and transmission delay are significantly reduced. To summarize, the contribution of this paper is: 1) A cost-effect MAC protocol FCM, which moves cooperative sensing and multi-channel contention from time domain into frequency domain. To the best of our knowledge, it is the first of this kind in the literature to address the control overhead problem in CRAHNs; and 2) Extensive simulations, which verify the effectiveness of FCM, and indicate that FCM can achieve throughput gain of 220% over Traditional Cooperative MAC for CRAHNs.

II. FCM DESIGN

In this section, we first present the basic idea and design challenges of FCM, Frequency domain Cooperative sensing

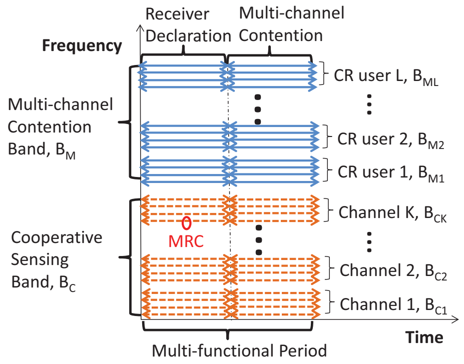


Fig. 1: Illustrations of Hierarchical Subcarrier Structure

and Multi-channel contention. Main strategies of FCM is then demonstrated to see how we address these challenges. Finally, we talk about some issues related to the design of FCM.

A. Overall of FCM

First, some necessary assumptions are summarized as following: 1) there are totally K adjacent data channels of interest $\{ch_i\}_k$. We assume full spectrum sensing ability for wide spectrum band, where CR users can sense all the channels at a short period of time [1]; 2) an error-free common control channel ch_0 is available for CR users at any time, which can be predefined in unlicensed band. All the cooperation and contention are undertaken in this channel; 3) we only focus on sparse to medium networks, with maximum $L = 15$ CR users in one collision domain. CR users get implicit synchronized as in [2] [3]; 4) each CR user is equipped with two half-duplex antennas, one is for listening and the other is for transmission.

With these assumptions in mind, we propose FCM to reduce the cooperation and contention overhead in CRAHNs. FCM utilizes OFDM as the PHY layer modulation scheme for common control channel ch_0. Taking advantage of OFDM subcarriers, more information can be encoded into one OFDM symbol. As stated in [3], we can obtain 256 or more subcarriers within a 20MHz channel. Thus the fundamental idea of FCM is: *to conduct decision sharing and multi-channel contention concurrently in frequency domain through OFDM subcarriers*.

The basic idea of FCM is simple and efficient, yet there remain several challenges for implementation. First, cooperative sensing and multi-channel contention are two individual processes, how to combine them together into a same period remains concern. Second, exchanging and sharing sensing decisions among different CR users consumes a considerable amount of time in CRAHNs, how can we accomplish this process with minimum time without degrading the sensing performance? Third, we can not simply apply frequency contention as in [2] in multi-channel scenario, since receiver has no idea which channel should be tuned to. Thus we should figure out how to conduct channel contention while notifying corresponding receiver in a cost-efficient way.

FCM has three strategies to address the above challenges: *hierarchical subcarrier structure* that integrates cooperative sensing and multi-channel together, *full-duplex Meta Reporting Channel* that conducts decision sharing, and *receiver declared contention* with order-matched multi-channel allocation. In the following subsections, we will present the design and functionality of these strategies.

B. Hierarchical Subcarrier Structure

In order to combine cooperative sensing and multi-channel contention together and move them into frequency domain, we propose a *hierarchical subcarrier structure* to conduct both of these two processes concurrently. Assuming there are N_S subcarriers in total for common control channel, which are numbered in ascending order starting with index 0 for the subcarrier at the lowest frequency. As shown in Fig. 1, in the first hierarchy, subcarriers are divided into two bands, termed cooperative sensing band B_C from subcarrier 0 to N_T and multi-channel contention band B_M from subcarrier $(N_T + 1)$ to N_S. Cooperative sensing band is used to exchange sensing information among CR users, and multi-channel contention band is used for contention and sender-receiver negotiation. In the second hierarchy, subcarriers are further divided into sub-bands and assigned to data channels and CR users respectively. Specifically, in cooperative sensing band, every N_C subcarriers are grouped into sub-band B_{Ci} and assigned to one data channel for its decision sharing. According to the FCC regulation, about 10 channels are available for portable device in TV white space. Therefore, $K \leq 10$. Similarly, in multi-channel contention band, every N_M subcarriers are grouped into sub-band B_{Mi} and assigned to one CR user for multi-channel contention. As we assume, $L \leq 15$. The sub-band distribution algorithm for data channels and CR users will be presented in Sec. II-C.

Instead of transmitting packets on these subcarriers, we use PHY layer signaling with Binary Amplitude Modulation (BAM) to transmit cooperation and contention messages. BAM modulates binary numbers “0” and “1” using on-off keying. Thus it is quite easy for CR users to demodulate BAM symbols using energy detection. As a tradeoff, the information contained in one BAM symbol is relatively small. To ensure the performance of both cooperation and contention, FCM utilizes two consecutive BAM time slots called *Multi-functional Period* for control transmission. Recall that each CR user has two antennas. Utilizing self-cancellation technique, a CR user can detect and decode BAM symbols from neighboring CR users with listening antenna, even it transmits its own BAM symbols with transmission antenna at the same time [2] [3].

C. Full-duplex Meta Reporting Channel

FCM leverages cooperative sensing band to undertake cost-effective decision sharing among cooperative CR users. In this paper we focus on the process after each CR user obtaining their individual sensing results. That is, how they exchange and share their sensing decisions to achieve cooperation gain. In FCM, CR users adopt hard combing as the data fusion rule, where binary local decisions are transmitted in cooperative sensing band. According to our *hierarchical subcarrier*

Algorithm 1 Construct $G(V, E)$.

```
for each two CR users $i, j \in V$ do
    if $i, j$ are within transmission range of each other then
        add an edge $e(i, j) \in E_1$
    end if
end for
for each edge pair $e(i, j), e(j, k) \in E$ do
    add an edge $e(i, k) \in E_2$
end for
$E = E_1 \cup E_2$
```

structure, we assign each data channel a unique sub-band B_{Ci}. CR users fuse their sensing decisions for each data channel in the corresponding sub-band. The sub-band distribution is conducted as following: we number the data channels in ascending order starting with index 0 for the channel at the lowest center frequency. Then each sub-band B_{Ci} is assigned to the i^{th} data channel, e.g., B_{C0} is assigned to ch_0.

In cooperative sensing band, a subcarrier in one BAM time slot is treated as a basic unit termed *Meta Reporting Channel (MRC)*, as stated in Fig. 1. Each CR user is assigned one *MRC* in each sub-band to transmit its decision for the corresponding data channel. Although *MRC* only has the capacity of 1 bit, this is just enough since the sensing decision for each data channel is a binary number. We formulize *MRC* allocation as a vertex-coloring problem, and construct an un-directional graph $G(V, E)$ using Algorithm 1, where V denotes all the CR users in the network and E represents the allocation conflict relationship among CR users.

Algorithm 2 Vertex coloring in $G(V, E)$.

```
Each node v executes the following code
v sends its ID to all neighbors
v receives IDs of neighbors
while v has an uncolored neighbor with higher ID do
    v sends "undecided" to all neighbors
end while
v chooses the smallest color not used by any neighbor
v informs all its neighbors about its choice
```

Problem definition: Given an undirected graph $G = (V, E)$, assign a color c_u to each vertex $u \in V$ such that the following holds: $e = (v, w) \in E \Rightarrow c_v \neq c_w$.

We adopts a Synchronous Distributed Algorithm with a total of $N_C * 2$ colors to do vertex coloring in $G(V, E)$. Each color represents one *MRC* in every sub-band. CR users operate in synchronous rounds, and in each round they execute Algorithm 2. This algorithm ensures that the neighboring CR users will not choose the same *MRC*, even in multiple collision domains. According to the coloring results, we assign one *MRC* to each CR user in each sub-band. The above algorithm needs (L+1) colors, which requires $N_C * 2 \geq (L + 1)$. Since $L \leq 15$ and $K \leq 10$, the bandwidth of B_{Ci}, $N_C \approx 8$ subcarriers, and the bandwidth of $B_C \approx 80$ subcarriers.

During the individual sensing period, each CR user makes local decision for all the data channels. When Multi-functional Period begins, each of them uses transmission antenna to transmit binary decision "1" or "0" on its own *MRCs* across all $B_{Ci}s$, where "1" represents the presence of a PU (H_1), and "0" represents the absence of a PU (H_0). Meanwhile, it uses listening antenna to acquire all the sensing results from others. Then each CR user applies a distributed fusion rule to obtain the cooperative decision. Here we adopt majority rule as the decision fusion rule. Advanced fusion techniques can be considered as future work to improve cooperative gain.

D. Receiver Declared Contention

CR users undertake contention in multi-channel contention band B_M during Multi-functional Period. Each of them is assigned one unique sub-band B_{Mi}. Here we directly apply the coloring results of *MRC* allocation in cooperative sensing band to B_{Mi} allocation. As the algorithm needs (L+1) colors, the bandwidth of B_M should be $(L+1) \times N_M$ subcarriers. In Multi-function Period, the first time slot in B_{Mi} is used for receiver declaration. We utilize hash value of the MAC address to represent a receiver. A sender will hash its receiver's ID into a value between $[1, 2^{N_M}]$ and transmit this value in its own B_{Mi}. "0" represents that a CR user does not have a receiver. Upon listening to this value, other CR users conduct the same hash function on its own ID to see if they are matched. Senders conduct contention in the second time slot. Each of them randomly picks up a number M from $[1, 2^{N_M}]$ as its contention number. "0" represents no contention at all. Meanwhile, every CR user use listening antenna to acquire others' contention numbers and construct a transmission order. The one with the smallest contention number has the highest priority to transmit, and vice versa. To ensure the contention space is large enough, we set $N_M = 10$ subcarriers. Then the contention space and hash space are both $(2^{10} - 1)$, which is sufficient for sparse to medium networks. The total bandwidth of B_M is around $(15 + 1) * 10 = 160$ subcarriers.

To decide which sender-receiver pair should transmit on which data channel, each CR user sorts the available data channels after it obtaining the final cooperative sensing decisions. The sorted available data channels have an ascending order in terms of channel index. Then we conduct order-matched multi-channel allocation for CR sender-receiver pairs. The sender-receiver pair with the smallest contention number (highest priority) will transmit on the available data channel with the lowest index. This allocation continues until there is no available data channel for transmission.

III. PERFORMANCE EVALUATION

In this section, we evaluate the performance of FCM through extensive simulations using self-defined network simulator. The simulations are divided into two parts. We first quantify the components of FCM, including Distributed Allocation Algorithm, cooperative sensing and multi-channel contention. Afterwards, the performance of FCM is evaluated comparing with Traditional Cooperative MAC for CRAHNs.

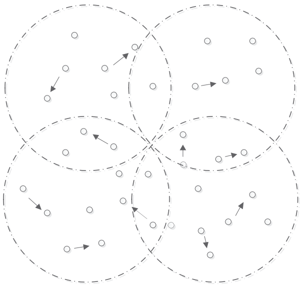


Fig. 2: Random topology with multiple collision domains, each domain with 5 to 15 CR users

A. Performance of Cooperative Sensing

Now we evaluate the performance of majority fusion rule for cooperative sensing. Each CR user has an average probability of miss detection P$_m$ and false alarm P_f for each data channel. We set the bandwidth of B_C to 80 subcarriers as discussed in Sec. II-C. The total number of data channels is 10. For each run of a simulation, we choose one collision domain from Fig. 2. All the CR users report their decisions for 10 data channels in B_C, and meanwhile receive decisions from others to conduct decision fusion. We compute the miss detection rate Q_{miss} and false alarm rate Q_{false} of cooperative sensing at each CR user for each data channel, and plot the mean of Q_{miss} and Q_{false} in Fig. 3 as functions of the number of cooperative CR users.

As shown in Fig. 3, cooperative sensing improves the performance of individual sensing under all the conditions. As the number of CR users increases, Q_{miss} and Q_{false} decreases, indicating that after cooperation, each CR user get a better understanding about whether the PU is present or not. Besides, the detection performance of individual CR user, P_m and P_f, has certain impact on the performance of cooperative sensing. When each CR user has a relatively high sensing accuracy, say $P_m = P_f = 0.1$, the cooperative sensing performance, Q_{miss} and Q_{false} are mainly below 0.025, which is nearly 400% cooperative gain. However, if each CR users has a relatively low sensing accuracy, say $P_m = P_f = 0.3$, higher cooperative gain can be achieved only if the number of cooperative CR users is relatively large. Therefore, to design a fusion rule with higher cooperative gain will be our future work.

B. Performance of Receiver Declared Contention

In this subsection, the performance of multi-channel contention is evaluated using the same topology and similar setting in Subsec. III-A. We set the bandwidth of sub-band $B_M = 160$ subcarriers. Since CR users contend in their own B_M bands, each of them knows exactly what contention numbers others have chosen. Thus collision on contention number will not result in collision on data transmission. But it does affect the transmission performance to same extant, as CR users with the same contention number will retreat transmission from this round. If this happens frequently, none of them is able to transmit. For each run of a simulation, we let CR users conduct contention. We compute the probability that two or more CR users choose the same contention number P_C under different bandwidth of B_M and different number of CR users.

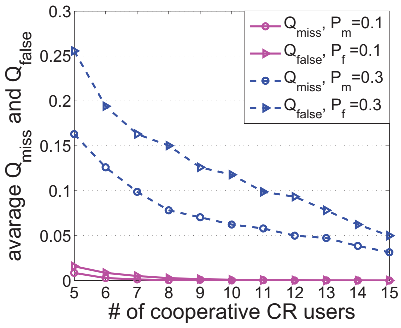


Fig. 3: Average miss detection rate and false alarm rate for cooperative sensing

Fig. 4 shows the contention probability in function of the number of CR users. Not surprisingly, as the number of CR users increases, P_C increases, since more CR users are prone to have more same choices. This probability can be reduced by increase the contention space, say, the value of N_M. When $N_M = 8$, the contention space is $2^8 - 1 = 255$, which results in a collision probability of 30% with the largest number of CR users. After we increase N_M to 10, this probability drops to only 10%, showing that each CR user has a larger chance to choose different contention number from each other. With this setting, the maximum number of subcarriers needed in multi-channel contention band is $N_M \times (L + 1) = 160$. And the maximum number of subcarriers needed for FCM, N_S is $80+160 = 240$, requiring a 256-point FFT OFDM modulation.

C. Performance of FCM

In this subsection, we quantify the performance of FCM comparing with the Traditional Cooperative MAC (T-MAC) in CRAHNs, which undertakes cooperative sensing and multi-channel contention in time domain. In particular, T-MAC assigns one time slot for each CR user in common control channel to report individual decision in sequential, and adopts 802.11 CSMA/CA for CR users to contend for each available data channel. This procedure is also shown in Fig. **??**. We use the parameters in Tab. I for T-MAC and FCM. There are total 11 channels with channel bandwidth of 20MHz. One channel is for common control, and the others are for data transmission. The PUs have a regular on-off pattern. The on and off durations are exponentially distributed with mean $50sec$. Each run of a simulation lasts $100sec$. Every CR user performs cooperative sensing, and we randomly pick up CR users from all the four contention domains in Fig. 2 to conduct contention and transmission in each run.

Fig. 5 depicts the average packet transmission delay with different number of CR users. The packet transmission delay is the time that a packet has waited for transmission. As for T-MAC, the packet delay increases as the number of CR users increases. This is because with more CR users, the time for reporting and contention becomes much longer. CR users need to go through a certain number of rounds before they win a

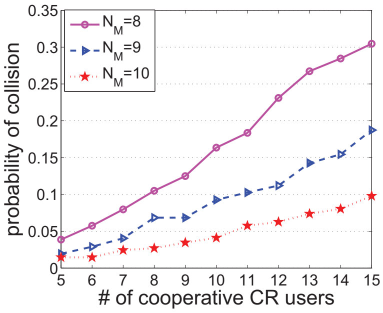


Fig. 4: Collision probability for CR users to choose the same contention number

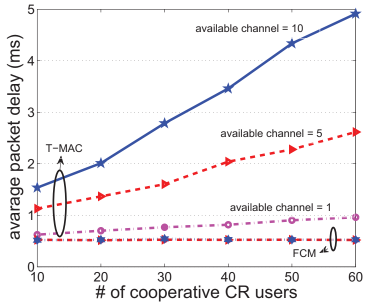


Fig. 5: Aggregate transmission delay with different number of CR users

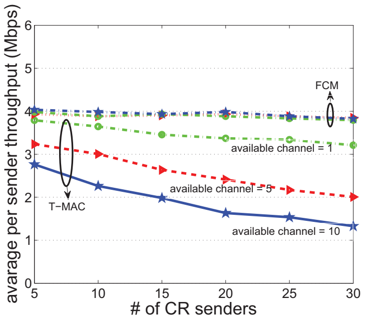


Fig. 6: Aggregate throughput with different number of CR users

TABLE I: Configuration Parameters

Parameters	Values	Parameters	Values
SIFS	16μs	Sensing time	500μs
DIFS	34μs	Packet length	1500bytes
Slot time	9μs	N_{FFT}	256 points
CW_{min}	16	N_C	80 subcarriers
CW_{max}	1024	N_M	160 subcarriers

data channel for transmission. Also, as the number of available data channel increases, delay also increases, since there are more data channels needed to be contended and negotiated. Meanwhile, the packet delay in FCM remains stable under all conditions, verifying the effectiveness that FCM only consumes two BAM symbols on control transmission. Thus it has very little packet delay, even with a large number of CR users and available data channels. Fig. 6 depicts the per sender throughput for both T-MAC and FCM. With T-MAC, throughput drops a lot as the number of CR users increases, resulting in a rather poor performance of around 1MBps. However, the performance of FCM remains satisfactory for all the conditions of around 4Mbps due to less control overhead.

IV. RELATED WORK

Many researches have been presented by minimizing the coordination overhead in common control for cooperative sensing. In [4], a censoring method is proposed to solve the bandwidth constraint in control channel, where a decision can be reported only after local test. In [5], the authors design an efficient combination scheme that allows reporting data to be superposed at the FC side. However, none of the above approaches takes contention overhead together into consideration, and reduces the overhead in frequency domain. Recently, some works [3] [2] leverage OFDM modulation to improve the efficiency of 802.11 MAC by moving the contention into frequency domain, such as T2F [2] and EPICK [3]. They reduce the MAC layer overhead by representing control information in frequency domain. Another type of work, like Side channel [6], uses “interference pattern” to reduce the control overhead without interference cancellation. And our previous work, ℏjam [7] and FAST [8] utilize interference cancellation to transmit both control information and data packets together. However, none of them utilizes frequency domain to reduce the cooperation and contention overhead in CR networks, which is the main target of FCM.

V. CONCLUSION

In this paper, we propose a novel MAC design FCM, Frequency domain Cooperative sensing and Multi-channel contention, to reduce the cooperation and contention overhead in CRAHNs. FCM leverages OFDM modulation to move both cooperative sensing and multi-channel contention from time domain into frequency domain, which significantly reduces the control overhead on cooperation and contention. Extensive simulation results show that compared with Traditional Cooperative MAC, FCM can achieve 220% throughput improvement, verifying the effectiveness of frequency domain cooperative sensing and multichannel contention. Next, we propose to validate FCM on SDR platform, and exploit it to benefit more communication systems.

ACKNOWLEDGMENT

This research is supported in part by HKUST Grant RPC10EG21, the 2012 Guangzhou Pearl River New Star Technology Training Project, NSFC-Guangdong Joint Fund (U0835004), the National Key Technology R&D Program (2011BAH27B01, 2011BHA16B08), and the Major Science and Technology Projects of Guangdong (2011A080401007).

REFERENCES

[1] I.F. Akyildiz, B. F. Lo, and R. Balakrishnan,“ Cooperative spectrum sensing in cognitive radio networks: A survey”, Physical Communication (Elsevier) Journal, 4 (1) (2011), pp. 40-62.

[2] S. Sen, R. R. Choudhury, and S. Nelakuditi, “Listen (on the frequency domain) before you talk”, in *ACM HotNets*, 2010.

[3] X. Feng, J. Zhang, Q. Zhang, and B. Li, ” Use Your Frequency Wisely: Explore Frequency Domain for Channel Contention and ACK”, in *IEEE INFOCOM*, 2012.

[4] C. Sun, W. Zhang, K. Letaief, ”Cooperative spectrum sensing for cognitive radios under bandwidth constraints”, in *IEEE WCNC*, 2007.

[5] X. Zhou, G.Y. Li, D. Li, D. Wang, A.C.K. Soong, “Bandwidth efficient combination for cooperative spectrum sensing in cognitive radio networks”, in *IEEE ICASSP*, 2010.

[6] K. Wu, H. Tan, Y. Liu, J. Zhang, Q. Zhang, and L. Ni. Side Channel: Bits over Interference. In *MobiCom*, 2010.

[7] K. Wu, H. Li, L. Wang, Y. Yi, Y. Liu, Q. Zhang, L. M. Ni,“hjam: Attachment Transmission in WLANs”, in *IEEE INFOCOM*, 2012.

[8] L. Wang, K. Wu, P. Chang, M. Hamdi, “FAST: Realizing what your neighbors are doing”, to appear in *IEEE ICC*, 2012.

A Distributed Infrastructure-Based Congestion Avoidance Protocol for Vehicular Ad Hoc Networks [§]

Maram Bani Younes*†, Graciela Roman Alonso*‡, Azzedine Boukerche*†
**PARADISE Research Laboratory*
† *DIVA Strategic Research Centre*
‡*Universidad Autónoma Metropolitana, Mexico*

***Abstract*—In order to detect and reduce the congestion level in downtown areas, many research works and projects have been proposed. The previous works have been based on the information gathered at a central database to recommend the best path for vehicles, which introduces a bottleneck problem as well as a single point-of-failure. In this work we propose a dynamic and real time protocol that intends to find the fastest path towards each destination in a distributed fashion, without the need for a centralized database. The proposed protocol recommends paths that will allow vehicles to avoid highly congested road segments towards a certain destination. Moreover, this protocol can alleviate the drastic increase in congestion scenarios by distributing the traffic load over the downtown grid road segments without adversely affecting the traveling time of vehicles. In this paper, we discuss our protocol in details, compare it to other path recommendation protocols and report on its performance evaluation an extensive set of scenarios and experiments implemented on the NS-2 simulator. From the results, we can conclude that our protocol provides better performance in terms of vehicular traveling time towards each destination, without the need for a central database.**

***Keywords*-Traffic Congestion, Congestion Avoidance, Congestion Control, ICODE.**

I. INTRODUCTION

The use of Vehicular Ad-hoc Networks ($VANETs$) communication to solve traffic-related problems has become very popular in the last few years [1]. Many protocols and mechanisms were proposed and introduced in order to reduce the road traffic congestion problem over downtown and highway areas. Many of these protocols aimed at finding the least congested path from the vehicle departure point to its destination [4], [5], [6], [7], [8], [9] in a static way. That means, the path can not be reconfigured if traffic problems arise when traveling. Those protocols have used a centralized database in order to collect and store vehicles' traveling history and applied data mining principles to recommend better routes.

Traffic congestion usually appears in downtowns, as a daily driving experience, mainly due to traffic accidents, construction works, bad weathers, potholes or obstacles. Moreover, using the same path towards the same destination by many drivers increases the congestion state at some of that path's road segments. Using a centralized database which is filled based on the vehicles' traveling history causes several issues. One of these issues is the fact that these protocols do not give an accurate nor a real-time recommendation, as road segments' traffic situation could change quickly. Moreover, using a central database introduces a bottleneck problem as well as a single point-of-failure problem, since all vehicles are intended to exchange packets with this central database, and the failure of this database could prove disastrous.

In this paper, we aim at introducing a dynamic route traveling protocol. This protocol introduces distributed recommendations to find the fastest path towards each destination dynamically. At each intersection, the path could be changed based on its surrounding Road Segments RS_is' situations. Each Road-Side Unit (RSU) gathers the predicted traveling time and the targeted destinations of its surrounding road segments traffic. After that, these RSUs communicate in order to find the fastest path (i.e. the least congested path) towards each destination based on the vehicles' traveling times and destinations in its surrounding road segments.

The remainder of this paper is organized as follows: in section II, we look at some of the related works done in the same field. In section III, we first introduce our two comparative distributed path recommendations protocols. Then we introduce our proposed protocol in section IV. The performance evaluation of our mechanism is presented in section V using extensive simulated scenarios. Finally, section VI concludes our paper.

II. RELATED WORK

Several researchers have investigated the traffic congestion problem in downtown and highway areas [4], [5], [6], [7], [8], [9] . Their research works aimed mainly at using $VANET$s communication to detect

---

[§] This work is partially supported by NSERC DIVA Strategic Network, Canada Research Chairs Program, and MRI/OIT Research funds.

the congested areas or to avoid highly congested paths during the vehicle trip [6], [9]. These mechanisms and protocols enhance the traffic fluency and decrease the expected trips' traveling time. For detecting congested areas, previous protocols gathered basic data about each specific area. Using these information, those protocols measure each area's traffic density or its traffic speed. Then, based on these measurements results, they evaluate that area's traffic congestion levels [2], [3], [12].

On the other hand, for recommending the least congested path towards each known destination, previous works use static protocols to find the path before the vehicle starts moving [8]. The turn decision is taken at each intersection based on the recommendations acquired from a centralized database [4]. In these works, moving vehicles are used to gather data about their path traffic congestion conditions, and report their traveling history to the centralized database at the end of their trip [7], [8].

However, these recommendation protocols do not provide real time data and therefore produce inaccurate least congested path recommendation due to use a relatively old database. Moreover, using a central database introduces a bottleneck as well as a single point-of-failure problems.

For the aforementioned path recommendation protocols' problems, we decided to design a protocol that aims at providing vehicles with accurate least congested path recommendations towards their destinations in a dynamic manner. To the best of our knowledge, this is the first protocol that uses a destributed multi-hop approach to recommend the best path towards each destination.

III. DISTRIBUTED PATH RECOMMENDATION PROTOCOLS

In this section, we present two suggested distributed path recommendation protocols: Simple Path Recommendation protocol ($Simple$) and Shortest Path Recommendation ($Shortest$) protocol. The proposed protocols are mainly based on fixed RSUs installed at each intersection in the downtown grid area. These RSUs are responsible for finding an alternative path for each vehicle's destination in their vicinity. These suggested protocols are used to have a comparative platform which shows the advantages of our proposed protocol in terms of decreasing the vehicles' traveling times.

A. Simple Path Recommendation Protocol

In this protocol, RSUs are cooperatively communicating in order to recommend a path towards each destination using an internal table with two main fields: (1) Destination ID, $RSU.Destin_i$, and (2) the next hop ID, $NEXTHOP_i$, to get to $Destin_i$. Each destination target periodically sends its advertisement message, $DesADV_i$. This message contains two main fields: (1) the Destination ID, $DesADV.Destin_i$, and (2) the sender RSU ID, $Node_{prei}$. $Node_{prei}$ stores the RSU ID which sent the $DesADV$ message. Whenever an RSU receives a $DesADV_i$ message initiated by a certain destination or a direct neighboring RSU for the first time, it adds that $DesADV.Destin_i$ to its $RSU.Destin_i$ field and $Node_{prei}$ to its $NEXTHOP_i$ field. Then, that RSU forwards an updated $DesADV_i$ message with a new $Node_{prei}$ value to all direct RSU neighbors (i.e. all RSUs that share a certain road segment with that forwarding RSU).

After that, if the RSU receives other $DesADV_i$ messages for the same destination from other neighboring RSUs, it will drop those messages. This protocol provides each RSU with path recommendations towards each destination without the need for too much communication overhead. Algorithm 1 explains this protocol in a more systematic way.

Algorithm 1: Simple Path Recommendation Algorithm

```
switch Received message do
    case $DesADV_j$ message from $Destin_j$
        $RSU_i$ adds a new record with:
        { $RSU_i.Destin_a = DesADV_j.Destin_j$;
        $RSU_i.NEXTHOP_a = NULL$ ;
        }
        $RSU_i$ updates $Node_{prej}$ field in the $DesADV_j$ message:
        { $DesADV_j.Node_{Prej} = RSU_i$;
        }
        $RSU_i$ forwards updated $DesADV_j$;
    case $DesADV_j$ message from $RSU_k$
        if $RSU_i$ receives $DesADV_j$ message for the first time then
            $RSU_i$ adds a new record with:
            { $RSU_i.Destin_a = DesADV_j.Destin_j$ ;
            $RSU_i.NEXTHOP_a = RSU_k$ ;
            }
            $RSU_i$ updates $Node_{prej}$ in $DesADV_j$:
            { $DesADV_j.Node_{Prej} = RSU_i$;
            }
            $RSU_i$ forwards updated $DesADV_j$;
        else
            drop the message.
        end

endsw
```

B. Shortest Path Recommendation Protocol

In this protocol, whenever an RSU receives a $DesADV_i$ message, it checks its database to see if it has any prior information about this destination target or not. In the case that, this destination target does not exist in its internal table, the RSU adds that destination's ID, $DesADV.Destin_i$, the next hop ID, $NEXTHOP_i$, and a newly added field, $DesADV.DIS_i$, into its database. This new field, $DesADV.DIS_i$, refers to the distance between the receiver RSU and the destination $Destin_i$. This field will also be updated and included in the successive $DesADV_i$ messages forwarded to the direct neighboring RSUs.

On the other hand, if the RSU database contains a record that is related to $Destin$, the RSU compares the distance value in its database $RSU.DIS_i$ to the distance value in the received message $DesADV.DIS_i$. If the $RSU.DIS_i$ is shorter than the $DesADV_i.DIS_i$, the RSU will drop this $DesADV_i$ message. Otherwise, the RSU should update its database regarding this destination, update the $DesADV_i$ message fields and forward the message towards its direct neighboring RSUs. Algorithm 2 explains this protocol in details.

Algorithm 2: Shortest Path Recommendation Algorithm

```
switch Received message do
    case $DesADV_j$ message from $Destin_j$
        $RSU_i$ adds a new record with:
        { $RSU_i.Destin_a = DesADV_j.Destin_j$;
        $RSU_i.DIS_a = Distance(RSU_i, Destin_j)$;
        $RSU_i.NEXTHOP_a = NULL$ ;
        }
        $RSU_i$ updates $DIS_j$, $Node_{prej}$ fields in the $DesADV_j$ message:
        { $DesADV_j.DIS_j = RSU_i.DIS_a$;
        $DesADV_j.Node_{Prej} = RSU_i$;
        }
        $RSU_i$ forwards updated $DesADV_j$;
    case $DesADV_j$ message from $RSU_k$
        if $RSU_i$ receives $DesADV_j$ message for the first time then
            $RSU_i$ adds a new record with:
            { $RSU_i.Destin_a = DesADV_j.Destin_j$ ;
            $RSU_i.DIS_a = DesADV_j.DIS_j + Distance(RSU_i, RSU_k)$;
            $RSU_i.NEXTHOP_a = RSU_k$ ;
            }
            $RSU_i$ updates $DIS_j$, $Node_{prej}$ in $DesADV_j$:
            { $DesADV_j.DIS_j = RSU_i.DIS_a$;
            $DesADV_j.Node_{Prej} = RSU_i$;
            }
            $RSU_i$ forwards updated $DesADV_j$;
        else
            if $DesADV_j.DIS_j < RSU_i.DIS_a - Distance(RSU_i, RSU_k)$ then
                $RSU_i$ updates the record related to this $Destin_a$ {
                $RSU_i.DIS_a = DesADV.DIS_j + Distance(RSU_i, RSU_K)$;
                $RSU_i.NEXTHOP_a = RSU_k$;
                }
                $RSU_i$ updates $DIS_j$, $Node_{prej}$ in $DesADV_j$:
                {
                $DesADV_j.DIS_j = RSU_j.DIS_a$;
                $DesADV_j.Node_{Prej} = RSU_i$;
                }
                $RSU_i$ forwards updated $DesADV_j$;
            end
        end

endsw
```

IV. THE PROPOSED CONGESTION AVOIDANCE PROTOCOL

The proposed protocol is also based on fixed RSUs that are installed at each road intersection in the downtown grid-layout. The difference in this protocol compared to the two previously mentioned protocols (i.e., Simple and Shortest Path Recommendation) is that each RSU gathers the traveling times and destinations of the vehicles in its surrounding road segments. This data could be changed dynamically under different considerations. The RSUs are responsible for finding the fastest alternative path for each vehicle's destination in their vicinity.

RSUs in this protocol also make use of internal tables. In this protocol, the RSU's tables contain three main fields: Destination ID, $RSU.Destin_i$, the Shortest Traveling Time, STT_i, towards this destination and the Next hop ID, $NEXTHOP_i$. These RSUs use their tables in order to recommend the fastest path for each vehicle heading towards a specific destination. We refer to the proposed protocol as Infrastructure-based COngestion avoiDancE protocol ($ICODE$) because it depends on Vehicle-to-Infrastructure ($V2I$) and Infrastructure-to-Infrastructure ($I2I$) communication.

Each destination target periodically sends its advertisement message $DesADV_i$. This message contains three main fields: (1) the Destination ID, $DesADV.Destin_i$, (2) the sender RSU ID, $Node_{prei}$, and (3) the estimated travel time, TT_i, from that RSU to get to $Destin_i$. When an RSU receives this message from one destination for the first time, it inserts that destination ID $DesADV.Destin_i$, the estimated travel time TT_i from that RSU to the destination, into the STT_i field and sender RSU ID $Node_{prei}$ in the $NEXTHOP_i$ field in its local database. After that, the RSU forwards that $DesADV_i$ message to its direct neighboring RSUs, with TT_i and $Node_{pre}$ updated fields, based on the RSU's surrounding road segments congestion levels.

In the case that, an RSU receives a forwarded $DesADV_i$ from one of its direct neighboring RSUs, it should check its table to get the information about that destination. If its table does not have any information about this destination, the RSU adds the fields related to this destination. Consequently, the RSU re-forwards an updated version of that $DesADV_i$ message towards its direct neighboring RSUs.

On the other hand, if its internal table contains information about this destination, the RSU should compare the STT_i field in the table with the TT_i field in the received $DesADV_i$ message. If the traveling time in the $DesADV_i$ message (TT_i) is less than the shortest traveling time in the hash table (STT_i), the RSU will update the record related to this destination. After that, it will re-forward an updated version of the $DesADV_i$ message towards its direct neighboring RSUs. Otherwise, the RSU will drop the message. Algorithm 3 explains our proposed protocol in a clearer and more systematic manner.

To the best of our knowledge, this is the first path recommendations protocol that does not use a central database. Moreover, this is the first protocol that could change the recommended path towards the destination in a hop-by-hop manner, which makes the detour decision at each intersection more accurate and dynamic.

V. PERFORMANCE EVALUATION

In this section, we show the results concerning the performance of our proposed distributed protocol. We compare $ICODE$ with the other aforementioned distributed path recommendations protocols, $Simple$ and $Shortest$ protocols, with respect to the communication overhead (i.e., number of transmuted messages and end-to-end delay), vehicles' traveled distance, and vehicles' traveled time.

These protocols were evaluated in a scenario where each RSU is meant to find an alternative path to three different destinations A, B, and C, located in a 4x4 Manhattan grid scenario, as shown in Figure 1. We consider this scenario as a simplified study situation which represents the extended case where a path is constructed from any node to get to any other different node in the grid-layout.

Algorithm 3: Congestion Avoidance Algorithm

```
switch Received message do
    case $DesADV_j$ message from $Destin_j$
        $RSU_i$ adds a new record with:
        { $RSU_i.Destin_a = DesADV_j.Destin_j$;
        $RSU_i.STT_a = ttime(RSU_i, Destin_j)$;
        $RSU_i.NEXTHOP_a = NULL$ ;
        }
        $RSU_i$ updates $TT_j$, $Node_{prej}$ fields in the $DesADV_j$ message:
        { $DesADV_j.TT_j = RSU_i.STT_a$;
        $DesADV_j.Node_{Prej} = RSU_i$;
        }
        $RSU_i$ forwards updated $DesADV_j$;
    case $DesADV_j$ message from $RSU_k$
        if $RSU_i$ receives $DesADV_j$ message for the first time then
            $RSU_i$ adds a new record with:
            { $RSU_i.Destin_a = DesADV_j.Destin_j$ ;
            $RSU_i.STT_a = DesADV_j.TT_j + ttime(RSU_i, RSU_k)$;
            $RSU_i.NEXTHOP_a = RSU_k$ ;
            }
            $RSU_i$ updates $TT_j$, $Node_{prej}$ in $DesADV_j$:
            { $DesADV_j.TT_j = RSU_i.STT_a$;
            $DesADV_j.Node_{Prej} = RSU_i$;
            }
            $RSU_i$ forwards updated $DesADV_j$;
        else
            if $DesADV_j.TT_j < RSU_i.STT_a - ttime(RSU_i, RSU_k)$ then
                $RSU_i$ updates the record related to this $Destin_a$ {
                $RSU_i.STT_a = DesADV.TT_j + ttime(RSU_i, RSU_K)$;
                $RSU_i.NEXTHOP_a = RSU_k$;
                }
                $RSU_i$ updates $TT_j$, $Node_{prej}$ in $DesADV_j$:
                {
                $DesADV_j.TT_j = RSU_j.STT_a$;
                $DesADV_j.Node_{Prej} = RSU_i$;
                }
                $RSU_i$ forwards updated $DesADV_j$;
            end
        end

endsw
```

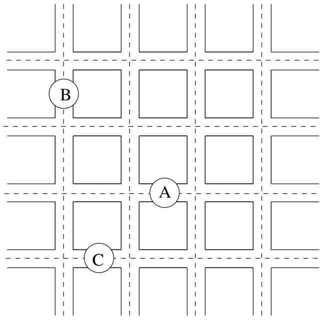


Figure 1. Manhattan grid scenario with three destinations

Table I
SIMULATION PARAMETERS

Parameters	Value
Road Segment Length (m)	200
Simulation Area (m x m)	1000 x 1000
Wireless Medium	IEEE802.11
No. of RSUs	16
Transmission Range (m)	250
Map Layout	4 X 4 Manhattan grid
No. of Road Segments	40 bidirectional

The performance evaluation of the proposed mechanism has been evaluated through an extensive set of simulation experiments using $NS-2$ [11]. The simulated parameters are illustrated in Table I.

In order to evaluate and compare the proposed protocols, we simulate different congestion level scenarios on some road segments. In general, we can classify these scenarios into five main categories: No (No congestion), Low, Medium, High and Heterogeneous Congestion scenarios.

In our experiments, the congestion level is determined by the traveling time per road segment. For example, in the No Congestion scenario, all RS_is in the downtown grid area have short traveling time. In Low, Medium, and High congestion scenarios, half of the grid area road segments are suffering longer traveling times with different levels; the more the congestion level, the longer the vehicles' traveling time within those road segments. The other half of this grid's road segments have no congestion and their vehicles' traveling time are relatively short. Finally, in the Heterogeneous Congestion scenario, half of the road segments have congestion ranging between low and high levels.

Regarding the communication overhead, Figure 2 and Figure 3 show the total number of sent messages and the end-to-end communication delay respectively, using the proposed three protocols with the previously explained five comparative configurations scenarios. From these figures, we can see that the $Simple$ protocol obtained the minimum number of messages and the shortest average delay time in all scenarios, since no re-forwarding of any $DesADV_i$ is required. The $Shortest$ protocol and our $ICODE$ protocol had the same number of messages and the same delay time value in the case where there is no congestion, since all road segments have the same vehicle's traveling time. This similarity is due to the fact that the fastest path is supposed to be the same as the shortest path in the ideal traffic congestion situation. However, when the difference of congestion among road segments is high, the $ICODE$ protocol has to generate more messages and needs more time in order to discover the fastest path. The segment's length is the same in our experiments, and therefore, the number of sent messages and the delay time by $Shortest$ protocol always remains constant regardless of the system congestion.

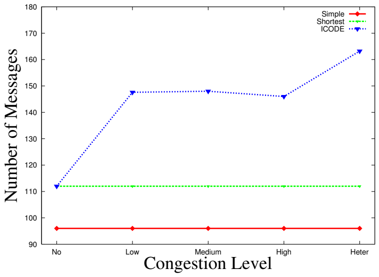


Figure 2. Total number of sent messages

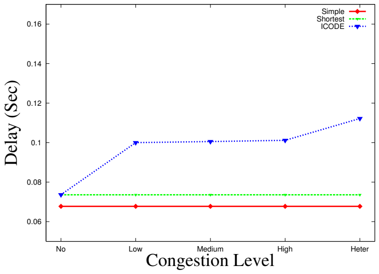


Figure 3. End-to-End communication delay

With respect to the traveled distance, we compute the average distances of the three paths from each RSU to get to the destinations A, B, and C. These results are shown in Figure 4. Using the $Simple$ protocol, which does not take into account the distance nor the traveling time to the destinations, we obtained higher traveled distances than using the $Shortest$ and $ICODE$ protocols. The $Shortest$ protocol got the best results concerning the traveled distance in the five scenarios. Also, we observed that the $ICODE$ algorithm obtained a traveled distance which was not as large as the one obtained by the $Simple$ protocol, instead, it was more similar to the $Shortest$ protocol having only an extra 10% of traveled distance.

The traveled time using $Simple$, $Shortest$ and $ICODE$ protocols, is presented in Figure 5. In this figure, the average paths traveled times by all nodes

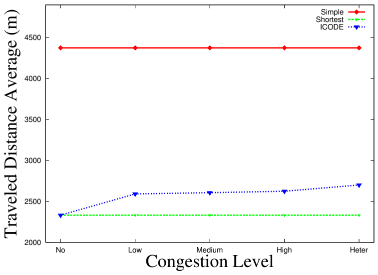


Figure 4. Average traveled distance

to get to the three destinations A, B, and C, are also illustrated. We clearly see that the $Simple$ protocol obtained longer traveled times, compared to the $Shortest$ and $ICODE$ protocols. We confirmed that the $Shortest$ and the $ICODE$ protocols behave similarly when working with the No Congestion scenario. However, when different congestion levels were presented on the grid, the $ICODE$ performed better than $Shortest$ protocol in terms of traveling time. From Figure 5, we can see $ICODE$ needs only 80% of the traveled time required by the $Shortest0$ protocol. Also, it needs only 30% of these required by $Simple$.

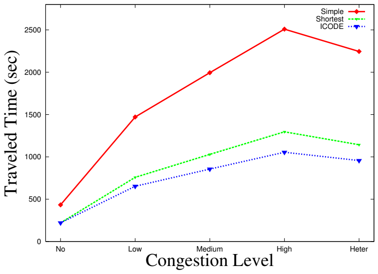


Figure 5. Average traveled time

VI. CONCLUSION

This paper proposed a protocol ($ICODE$) that aims at reducing or avoiding the traffic congestion situation within downtown areas. $ICODE$ recommends an alternative path for each given destination based on road segments' congestion situations. The protocol is based mainly on $V2I$ and $I2I$ communication, where RSUs act as the infrastructure installed at each intersection on the downtown grid scenario. Each RSU uses vehicles' traveling time parameters in its surrounding road segments to recommend an alternative least congested path towards each destination.

$ICODE$ was compared to other introduced distributed path recommendation protocols comparative platform, $Simple$ and $Shortest$ protocols. From this comparative simulation, find that $ICODE$ decreases the average vehicles' traveling time towards their targeted destinations by 20% comparing to the $Shortest$ protocol and 70% comparing to the $Simple$ protocol. However, with respect to a communication overhead, it is apparent from the results that $ICODE$ needs a larger number of messages and more time to recommend the path. As future work, we aim at reducing that overhead.

REFERENCES

[1] A. Boukerche, *Algorithms and Protocols for Wireless and Mobile Ad Hoc Networks*, Wiley & Sons, 2008.

[2] S. Dornbush, and A. Joshi, *SmartStreet Traffic: Discovering and Disseminating Automobile Congestion Using VANET's* Vehicular Technology Conference, pp. 11-15, 2007.

[3] J.Fukumoto, et al, *Analytic Method for Real-Time Traffic Problems by Using Content Oriented Commuincation in VANET* 7th International Conference on ITS, pp. 11-15, 2007.

[4] S. Inoue et al., *An Automobile Control Method for Alleviation of Traffic Congestion Using Inter-Vehicle Ad Hoc Communication in Lattice-Like Road*, in IEEE Globecom Workshops 2007, (Washington DC, USA), pp. 16, 26-30 Nov. 2007.

[5] R. Morla, *Vision of Congestion-Free Road Traffic and Cooperating Objects*, Citeseer, 2005.

[6] A. Lakas, and M. Cheqfah, *Detection and Dissipation of Road Traffic Congestion Using Vehicular Communication*, Proc. of IEEE 2009 Mediterrannean Microwave Symposium, Tangiers, November 2009.

[7] K. Collins and G. M. Muntean, *A Vehicle Route Management Solution Enabled by Wireless Vehicular Networks* in INFOCOM Workshops IEEE, pp. 1-6, 2008.

[8] X. Zhang et al, *A Novel Real-time Traffic Information System Based on Wireless Mesh Networks* in Intelligent Transportation Systems Conference, ITSC 2007. IEEE pp. 618 - 623, 2007

[9] B. Schunemann, J. Wedel, and I. Radusch, *V2X-Based Traffic Congestion Recognition and Avoidance* Tamkang Journal of Science and Engineering, Vol. 13, No 1, pp. 63-709, 2010.

[10] L.D. Chou, D. Li, and H. Chao, *Mitigation Traffic Congestion with Virtual Data Sink based Information Dissemination in Intelligent Transportation System* in Ubiquitous and Future Networks (ICUFN), Third International Conference on, pp: 37-42, 2011.

[11] "Network Simulator nss-2," *http://www.isi.edu/nsnam/ns/.*

[12] F. M. Padron, *Traffic Congestion Detection Using VANET*, Thesis (M.S.C.S.)–Florida Atlantic University, 2009.

[13] G. Korkmaz and E. Ekici, *Urban Multi-Hop Broadcast Protocol for Inter-Vehicle Communication Systems* in VANET '04 Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks, 2004.