

Future Wireless Cities Workshop Report

Workshop chairs:

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1. Summary:

This is a report summarizing the major findings and recommendations from the NSF-sponsored “Future Wireless Cities” Workshop held on Feb 2-3, 2016. Emerging wireless network services are expected to pervade domains such as healthcare, transportation, civic services, public safety, education and entertainment, and can thus be considered essential infrastructure much like water, electricity or sewage. A future wireless city is envisioned as a dense deployment of programmable/heterogeneous wireless access technologies backed up by software-defined infrastructure networks, novel network architectures and edge-cloud services. While the above objectives are being addressed to some extent in industry and standards forums such as “5G”, “IMT-2020” and “MEC”, rapidly changing core technologies (such as SDR, SDN, virtualization, cloud) have created the right conditions for disruptive breakthroughs in the design of future wireless systems. The “wireless city” is viewed as an “in-situ” testbed that provides sufficient density, scale and realism to explore and validate new concepts. To meet the ever increasing demands of higher, better, and faster connectivity, the next major research initiative in the domain of wireless systems, networking, and communication for the next decade, needs to be conducted such that researchers can evaluate techniques, technologies, and systems at scale --- spanning across an entire city¹.

The scope of the workshop included ideas for future wireless network architecture, key technologies and algorithms, testbed realization, cloud service integration, and application concepts/use cases. The meeting was attended by about 60 people including about 45 academics, 6 industry researchers/executives, 5 representatives from smart city projects and 10 representatives from NSF and other government agencies. The 2-day workshop agenda was organized as follows:

- 1) Technical sessions on new ideas for architecture, network technologies & cloud services with 3-4 speakers in each followed by a discussion period. Each

¹ The term city broadly refer to communities and populations, which could be of different sizes and either urban and rural.

- technical session included a short keynote talk by distinguished speakers including Craig Partridge (BBN) and Henning Schulzrinne (Columbia).
- 2) A session for input from industry, providing workshop attendees with a sense of current technology trends and future R&D plans. Industry representatives were present from Nokia, Cisco, Nokia Bell Labs, GM, Verizon and Qualcomm.
 - 3) A session for input from cities with smart city projects, providing workshop attendees with a sense of ongoing city-scale initiatives. Cities represented included Ammon, ID, Philadelphia, PA, Chattanooga, TN, Flint, MI, Chattanooga, TN, and Burlington, VT.
 - 4) A session on experimental infrastructure with presentations on current and future testbeds and ideas for future wireless city environments. Participants included representatives from GENI and Internet2.
 - 5) Two pairs of breakout sessions (one on day 1 and the second on day 2) on research agenda and experimental infrastructure respectively. The research breakout sessions were co-chaired by Prof. Peter Steenkiste (CMU) and Yanyong Zhang (Rutgers), while the infrastructure breakout sessions were co-chaired by Profs. K.C. Wang (Clemson) and Jie Wu (Temple).

Key recommendations emerging from the workshop are summarized below. More details of the topics discussed and the recommendations are given in Sections 2 and 3 that follow.

SUMMARY RECOMMENDATIONS:

R1: NSF should continue to support and/or develop research programs on the following wireless cities research challenges. Each of these topics has significant potential for academic research leading to architecture or technology breakthroughs for next generation wireless systems.

- Shared spectrum access in dense urban environments
- Integration of computing and networking for mobile edge cloud scenarios
- Next-generation wireless protocols ("5G") both in terms of advanced functionality and the introduction of programmability/virtualization.
- Architectural research on future wireless systems addressing fundamental challenges of scale, latency, security, robustness and usability.
- Internet-of-Things (IoT) and Cyber Physical System (CPS) system design for emerging city-scale applications including transportation, healthcare and energy.

R2: City scale wireless testbeds are important to meet significant future research needs, based on the following considerations.

- There was a clear consensus that the increasing emphasis on experimental research in the recent years has led to critical breakthroughs in wireless and networking.
- The last decade has seen the community move from mostly simulation and modeling based research to the development of practical. It has become clear that the effects of large scale, of complex interactions among large numbers of applications are critical to the design of wireless systems, yet increasingly hard to model at scale via simulation.
- It was accepted that experimental testbeds are needed to capture important city characteristics such as real end users, real usage patterns (e.g., time of access, mobility, application traffic), and physical infrastructure (e.g., radio cells, vehicle platforms, infrastructure-assisted wireless).
- Such testbeds must span multiple domains and city geographies as opposed to single campuses (as done in GENI before).

R3: NSF and the research community should work towards development of open, programmable, large scale wireless city testbeds in collaboration with industry and ongoing city projects as well as other government agencies. The “stars are aligned” for city-scale wireless research because of the following observations:

- Simplified FCC rules for experimental spectrum and the availability of new frequency bands such as 3.5 Ghz and mmWave, making it possible to deploy broadband wireless technologies such as LTE and future 5G.
- Increasing city-level investments in broadband, and public-private partnerships such as US Ignite to develop new services, and a willingness by cities to serve as host for future deployments
- Industry focus on “5G” technology and services has significantly improved prospects for incorporating advanced technology into city scale testbed(s).
- Emerging programmability and virtualization technologies for wireless such as NFV, SDN, open LTE and cloudRAN are expected to enable a great deal of experimental flexibility previously considered impossible.

R4: The city testbeds are much more than radios. They must consist of sliceable and software programmable clouds, network infrastructure, radios and real-world end users.

- Programmable radios allow for significant research and experimentation opportunities.
- Creative solutions in collaboration with industry will be required for development of low-cost mobile devices with the right form factor and power consumption for widespread deployment.
- The success of infrastructure at such scale requires the alignment with industry/open source 5G, SDN, NFV R&D efforts, exploration of new

opportunities in spectrum, from existing commercial bands to 3.5G to others, and finally the need to study range of client devices and infrastructure.

- Multiple testbeds in parallel may increase probability of success. Sufficient critical mass investment will be required to ensure success of deployment.

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R5: Develop a framework for shared testbed operations and management.

- Infrastructure of such scale cannot likely be managed by individual academic entities. It requires establishment of suitable partnerships of different types.
- It requires academic institutions to work with local government (from local communities), and with industry that have suitable experience in managing such infrastructure. Incentives have to be created and aligned that leads to a fair, yet win-win, structure for all.

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R6: Start a planning process to evaluate the wireless cities opportunity and propose a specific plan for moving forward

- While discussions at the current workshop outlined some broad directions for the creating such infrastructure, it is clear that a significant planning phase is necessary to move this process forward.
- The first key step is to identify key research directions and related testbed requirements that cannot be addressed with current infrastructure.
- Requirements for the testbed(s), experiment capabilities and responsibilities must be defined; key partners must be identified with a centralized, holistic approach, potentially engaging the industry, US government agencies, US Ignite cities, non-profits, and network operators such as Internet2 and regional networks.
- Inter-disciplinary researchers with complementary expertise across applicaion domains should be engaged, e.g., sociologists, architects, public health, and more.

2. Research agenda:

The research breakout sessions identified the following major challenges related to the wireless cities theme:

2.1 Shared Spectrum Access:

Lack of available spectrum is a serious and growing impediment to expanded use of wireless devices. This spectrum crisis was recognized in the U.S. National Broadband Plan, and even the President of the United States in a presidential memorandum. One research challenge involves using high-frequency spectrum such as mmWave in new and better ways. Another way to address the problem is through dynamic spectrum sharing arrangements, in which different wireless systems that might otherwise get their own spectrum allocations somehow coexist in the same band. Spectrum sharing techniques are needed not only for coexistence with legacy primary users, but also to support potentially novel sharing models in newly allocated bands. The solution is likely to require a change in wireless technology, and a change in the spectrum management policies and regulations that are intertwined with technology. In addition, sophisticated spectrum monitoring will be needed to detect spectrum sharing violations and to support data-driven optimization.

Wireless smart cities have the potential to exacerbate the problems of spectrum availability, and the potential to advance research that will help. Smart cities exacerbate the problem because they will require many more wireless devices that place additional demands on the spectrum. Moreover, some of these devices may have different spectrum needs. For example, sensors embedded in city infrastructure may operate for years on a single battery, so the typical methods of communicating with distant servers are unacceptable because of power limits, and this has implications for spectrum management. Further research is required on spectrum needs for smart cities. At the same time, because a smart city can include wireless infrastructure deployed for the purpose of improving methods of accessing spectrum, and spectrum bands that are set up for experimentation, important spectrum research is possible.

2.2 Mobile Edge Clouds:

A major research challenge is to enable a live city snapshot, which supports city analytics, decision-making, infrastructure control, and nudging of human behavior at the macroscopic and microscopic level in real-time. This will require integrating a large, heterogeneous set of Internet of Things and mobile wearable devices that provide data in many different data formats. Aggregating data at this scale will benefit from edge

computing. It will also require solving system issues such as those around identity and security at scale. In particular, it will be necessary to build security solutions on the identity building blocks emerging in current future network architectures. City-scale deployment will place greater demands also on the usability of these security solutions. Another major research challenge is meeting the tight latency requirements of future applications. Latency and robustness constraints must be met in an open environment and within a collection of interacting systems rather than in a dedicated stovepipe architecture. Applications will require updating state and coordinating among any devices in real-time, for example among traveling vehicles and the surround traffic control infrastructure. Mobile devices will also need to offload compute intensive tasks to “cloud” resources, which may range from highly centralized but remote cloud data centers to nearby cloudlets, depending on the latency, computational, and other requirements. It will also be necessary to render policy decisions within these latency bounds. This requires methods for policy specification and reasoning about them. It is likely that the resulting network architecture to meet these needs will be more distributed and place computing functions closer to the network edge. Such an architecture would also require methods for more efficient remote management and for offering strong reliability guarantees.

2.3 Next-Gen Wireless Protocol Research

One primary challenge in the area is how to enable programming and/or experimentation of the wireless networks of the future with real users across real networks. While the notion of programmability is intrinsically linked to the notion of a testbed, there are considerable challenges for academics and even industry to explore or consider alternatives that represent incremental much less radical changes to the core of the network. A foundational question emerges with regards to whether isolation / slicing / programmability is merely needed for academics or more importantly whether said characteristics are intrinsic to meeting the needs of the next generation of wireless networks.

A second major protocol design challenge is the notion of Lights Out Network management that incorporates wireless networking. Whereas there have been some work done on self-optimizing networks within a particular wireless technology, the notion of end-to-end Lights Out Management across multiple wireless technologies would represent a transformative but necessary chasm to cross to enable the wireless networks of the future. The notion of a wireless network that “just works” encompasses a host of research problems ranging from device heterogeneity to

technology heterogeneity to environmental heterogeneity that need foundational research at a city-wise testbed level.

Finally, there is a significant need to continue reexamination of network fundamentals, particularly with regards to the complex control interactions that emerge within larger systems (such as FIA or 5G). While cellular is widely regarded as excessively complicated, it is functional. Conversely, the notion of a minimalist network stack has emerged for IoT thinking about IP, TCP, HTTP, and DNS. There is fundamental research needed with regards to systematic design of control protocols and their various interactions capturing the tradeoffs appropriate for the various solution domains. For example, what is the minimal functionality for a control protocol that marries say LTE and WiFi or new 5G wireless links? How might an inexpensive IoT sensor need to be controlled versus say a smartphone? Where might the division of labor with regards to security be spent? There is a significant need for a systematic approach to address these foundational questions with regards to protocol design as it applies to wireless and even wired networks and the testbeds moreover to evaluate said approaches.

2.4 Internet of Things (IoT) and CyberPhysical Systems (CPS)

Several speakers at the workshop pointed to the importance of emerging IoT and CPS scenarios such as vehicular networks, transportation systems, smart grid, healthcare and so on. Further, there is a growing sense that low latency and high reliability will become even more important as these applications (many of them real time) proliferate into daily life in a city. Some of the research challenges associated with IoT and CPS are architectural, requiring a re-balancing of functions carried out between devices, networks and clouds. As an example, much of the current focus on self-driving cars is on fully autonomous operation, but there may be value in increasing the role of roadside information infrastructure including networks and clouds. Real-time applications such as augmented reality will also require innovative methods for providing seamless services during user mobility. In addition to architectural challenges, IoT and CPS motivate further research on topics such as energy efficient radio access, peer-to-peer communication modes and low-latency/low overhead networking to mention a few.

3. Testbeds and Experimental Infrastructure:

This section starts with a discussion of testbed or experimental infrastructure requirements for each of the research topics discussed above in Sec. 1. These topics were discussed by participants in the research breakout, with the objective of identifying key requirements for the city scale testbed.

3.1 Spectrum Research Testbed Requirements:

To devise effective schemes to use spectrum efficiently, we need a deep understanding how spectrum is actually being used. A highly instrumented wireless city could allow us to observe spectrum utilization by different types of devices to a higher degree of granularity than has previously been possible. It would allow us to measure the noise floor, and how it changes over time and space. Instrumentation would also enable new research on what is and what is not observable. This is important because spectrum sharing will not work unless spectrum policies can be enforced, and enforcement is often possible only when violations can be detected under realistic conditions.

Observation is a start, but further progress on novel forms of spectrum sharing would be possible through experimentation with devices that can both transmit and receive. A wide variety of sharing schemes are possible, perhaps making use of many different spectrum bands at different times. This requires devices capable of coordinating with those devices they wish to communicate with, while avoiding those that they don't. Such schemes could be evaluated experimentally if there were spectrum bands set aside for this purpose, for which there was little risk of interference to systems in adjacent frequency bands or geographic regions. Ideally, this would also involve programmable wireless devices capable of operating in many spectrum bands that are inexpensive to researchers, and that are sufficiently similar that they can be used and shared with research labs all over the country.

A wireless smart city would also provide an opportunity to try spectrum-sharing schemes that involve coexistence with legacy systems, i.e. systems that are already in use with technology that cannot easily be changed. For many such systems, it is not practical to recreate realistic systems in a laboratory environment, perhaps because deploying a realistic legacy system solely for the purpose of experimentation would be quite expensive, e.g. if one must build an entire TV broadcast tower just for research, and perhaps because the realism requires the wireless system to be in actual use. In such cases, researchers need to access spectrum that is already in use by prominent

legacy systems, albeit in a manner that protects these legacy systems from unacceptable degradation in quality of service.

The group also discussed the use of university campuses for smart city testbeds. FCC rules give university campuses a fair bit of flexibility in spectrum use which may simplify many of the experiments that are envisioned. Moreover, it simplifies engaging students at all levels to participate in, and contribute to, the research and experiments, which might broaden participation in the research, in addition to providing educational benefits.

3.2 Mobility and Cloud Computing Testbed Requirements

Both these challenges will benefit from a city-scale testbed since a key factor is the density of devices, realism, and the heterogeneity of the interacting systems. The value of testbeds can lie in collecting data under varied realistic conditions, in validating models through experiments, and in experimentally exploring performance issues at scale. Based on these considerations, testbeds should be carefully tailored to the research hypotheses that are to be tested. This is easier to achieve with a group of loosely federated testbeds, where each testbed is precisely targeted at a research objective, rather than with one single integrated testbed. More specifically, research on mobility services and edge clouds will require programmable access to both access networks such as LTE or WiFi along with the ability to co-locate edge clouds close to these access networks. While GENI and other projects have moved the community closer to this capability, further development and deployment will be required to provide sufficient programmability and scale for experiments with LTE and emerging 5G wireless access networks. The city testbed architecture would also need to provision for edge cloud deployments close to mobile users in order to answer key questions about architecture.

3.3 Next-Gen Wireless Testbed Requirements:

Scale introduces the need to deal with device / environmental / network heterogeneity and more importantly, heterogeneity with regards to virtualization / slicing support. The city-wide testbed represents a true test of whether said slicing and / or techniques are truly necessary for deployment at said scale or merely a design necessity for research. Moreover, a city scale truly tests the ability of the approach to at a minimum blend seamlessly with existing wireless services.

For requirements including E2E LOM, Systematic Control Protocols, the city-wide testbed is essential. The city-wide infrastructure provides the ultimate test case for

dynamics and use cases in that the number of networks, devices, and environmental cases that one user experiences across a day would be potentially significant. In particular, control problems that emerge not only with E2E LOM and generalized control are likely to only be evident at scale, emergent properties that would be extremely difficult to simulate and / or experience in the lab.

Multiple testbeds scattered geographically across a variety of densities would be ideal to allow for both low-impact / validation testing coupled with larger scale / higher impact testing.

There exists no such analog as the notion of a “radio slice” is non-existent. Nearly all wireless devices are closed and inaccessible to the researcher. The notion of an open hardware exists with software-defined radio but is often too slow / expensive for effective testing with real users. Foundational work is needed to realize said platform as it opens a host of research opportunities.

The remaining two areas require more so access than foundational changes to the devices. In some sense, the second two approaches could work with running agents on existing devices. Critically though, both approaches would need access to infrastructure data, a data source that is typically not accessible to a researcher as the mobile device side is insufficient to understand the macro-view of the overall system. Both could be addressed with access that would come with a city-wide testbed.

3.4 General Comments on Testbeds: The research breakout concluded with a short discussion on broader testbed requirement, i.e., not specific to a research topic. There was no consensus in the group on what an ideal testbed strategy might be. Several people expressed concern that testbeds that were too narrow may see very low utilization. On the other hand, there was also concern that a single large testbed that is designed to support all or most of the research activities described earlier in this section could become very complex and it may become very hard to manage both the infrastructure and the experiments that need to share the testbed. Finally, it was pointed out that a dense testbed of programmable devices might be able to support a wide variety of experiments. The platform should be able to operate across a wide range of frequencies (supporting dynamic and shared spectrum access research), be programmable (protocol research), while offering libraries for widely used protocols (to support domain specific research such as IoT).

3.5 Testbeds Breakout Discussion:

The Experimental and Testbed Needs breakout session discussed the key emerging wireless research areas, specifically in a city context, and the experimental infrastructure needs that are critical for significant research advancements. By design, this workshop did not include discussion of the radio technologies research; instead, focus was placed on how such emerging radio technologies interact with the network and applications they enable. As such, the discussions were clearly driven by applications, ranging from 5G mobile communication, cyber physical systems (CPS, e.g., connected vehicles, UAVs), Internet of Things (IoT, e.g., sensor networks in smart infrastructure, smart grids).

- Significance of city scale wireless research
 - A clear consensus was felt throughout the discussion that the increasing emphasis on experimental wireless research beyond laboratory has been a critical breakthrough in the wireless research community (as observed in top wireless research conferences such as MobiCom). While theoretically, wireless systems can be simulated with layered models, it has become clear that the effects of large systems scale, of complex interactions among large numbers of applications and of perturbations caused by such large, complex interactions are increasingly critical to the design of wireless systems, yet increasingly hard to model at scale via simulation. It is agreed that experimental testbeds are needed to capture important city characteristics such as real end users, real usage patterns (e.g., time of access, mobility, application traffic), and physical infrastructure (e.g., radio cells, vehicle platforms, building-assisted wireless).
- Key components and resources
 - Across the range of applications discussed, it is apparent that despite the different radio front ends that'd be involved, there emerges the need for the following resources – distributed cloud reaching all the way to the network edge, interconnected with the radios over software programmable networks including the IP network. Both the computing, network, and radios are expected to be “sliceable/virtualizable”, so as to support parallel experimentation of heterogeneous technologies *as well as*, potentially, production of city services provided by partnering commercial operators. A monitoring infrastructure, either embedded in

- or separate from the experimental systems, is critically needed both for verification of research measurements and for detecting unintended behaviors such as a runaway, rogue radio radiating in unacceptable spectrum. Wireless spectrum is certainly a critical resource, from current commercial bands to the emerging mmWave bands. FCC was represented in our discussion and shared encouraging remarks about increasing flexibility of research use of spectrum (e.g., 3.5 GHz band was recommended, visible light, and fiber optical spectrums included), including the upcoming opportunity for city scale research experiments.
- Finally, real users and real applications are crucial to enable meaningful city scale experiments. Nevertheless, engaging real users incurs in many challenges, from managing the user demand for privacy, data ownership, opt-in policy, and compliance with the institutional review board (IRB) provisions. Optical network is yet another component with significant emerging interests, given the critical role it plays as the backhaul for broadband wireless edge.

 - The group pointed out the impressive, timely synergy of multiple industry and open source community initiatives in 5G, SDN, and NFV. It is imperative for the academic research community to engage with these initiatives as early as possible to make impactful contributions. There is also a broad range of wireless client and infrastructure platforms of different form factors – from commercial devices to test devices, to experimental hardware – that can be studied for inclusion for different research purposes.
- Significance of slicing/virtualization
 - Virtualization is a critical requirement for all components in a city scale testbed, for parallel experimentation, and for coexistence of production service (to enable city and commercial partners' applications).

 - Partners
 - City scale testbeds are a major undertaking that requires significant funding, city support (e.g., deployment over city property, right of way), support for creating, distributing, and managing large number of real end users with their test devices. At the same time, city scale testbeds are of high value to other government agencies, such as USDOT's smart city challenge that emphasizes need for wireless connectivity for vehicles and

roadside infrastructure. The infrastructure can also provide city residents with much needed connectivity and services through the virtualized testbed. This can be critical incentives for cities to commit significant resources as a partner. Universities, many of which are closely integrated with the city, can be important partners as well.

- Development strategies
 - Clearly, to plan for a testbed for long range research is challenging. It is important to provision and design the testbed with maximal flexibility. It is recommended that multiple testbeds instead of one can be considered to support different types of research, if the research requires specialized resource or configuration. For each testbed, the design will strive to maximize modularity to accommodate different research technologies. The successful spiral approach adopted by the NSF GENI project can be a good and agile model for continuously evolving the testbeds to better designs and/or newer technologies.

- Data ownership
 - Testbeds must overcome data and privacy hurdles, because of concerns related to security and compliance with privacy rights. Not all data is created equal. Different data may require different degree of security. For example, geographic location aware data likely requires a higher level of security than pedometer data or atmospheric pollution content.

3.6 Session on Wireless City Deployments:

After the flexibility of campus testbeds for early research, the natural locations for more realistic wireless testbeds are willing and adventurous cities. These are often cities surrounding college campuses who are willing to “live in the future” by trying out new technologies and services. US Ignite is one good source of such cities. It’s easy to find cities of appropriate size and scale to match the desired testbed. They naturally incorporate the features that vex realistic wireless deployments such as buildings, varied natural topography, difficulty in locating base stations, and so forth. But they also have real users and real applications and those users will incorporate their natural day-to-day mobility as part of the testbed.

US Ignite cities are good choices for wireless testbeds because they have:

- The support of their civic leaders and Chamber of Commerce
- The support of a strong local university

- City-wide fiber which can be used to support experimental base stations at high bandwidth and low latency and close spacing
- A digital town square with software-defined infrastructure that can be used to support software-defined eNodeB and EPC functions

The city scale is often comparable to typical commercial deployments although it's also possible to use a portion of a city, perhaps a portion near the university. There may be some opportunity to request an FCC waiver to extend the authority given to educational institutions to operate unlicensed wireless on their own grounds to nearby areas in their city if there are no objections from the city or businesses or homes in the extended area.

Six cities participated in the workshop and all agreed that they would be eager to have their city involved in a wireless testbed.

City	Accept wireless testbed	Unique characteristics	Academic Institution	US Ignite City
Chattanooga, TN	Yes	10 Gbps fiber throughout the city	U. Tennessee	Yes
Burlington, VT	Yes	Compact size; fiber throughout	U. Vermont	Yes
Ammon, ID	Yes	Educated and motivated citizens work at Idaho Natl Labs; fiber throughout	Arrangement with U. Utah	Yes
Kansas City	Yes	IEEE Smart City; Cisco Smart+Connected City	UMKC, U. Kansas	Yes
Philadelphia, PA	Yes	Community Learning Centers	Drexel U., U. Penn	No
Flint, MI	Yes	Wireless research; interesting topography	Kettering U.	Yes

Building-assisted Wireless: An intriguing research topic is to rethink the role of buildings in wireless networks. They are most typically thought of as impediments to wireless propagation inside and multi-path surface reflectors outside. But they needn't be that way. New buildings being constructed or older buildings being renovated could embrace and enhance wireless technologies. Just as buildings offer built-in access to utilities such as power, heating/cooling, and water/sewer, they could offer explicit support for wireless communications utilities.

3.7 Industry Input Session: The industry session had short 10-min talks by speakers from Nokia, Cisco, Verizon, Bell Labs, Qualcomm and GM. Each of the industry speakers highlighted the importance of emerging "5G" technology solutions for next-generation wireless. The applicability of 5G systems to emerging smart city applications was discussed and key features of the technology such as improved spectrum efficiency, gigabit per second radios, low-latency access networks, enhanced network architecture/services were identified. The importance of Internet-of-Things (IoT) application scenarios for smart cities was addressed by several speakers, and equipment companies such as Nokia, Cisco and Qualcomm explained how their planned 5G products would fit into the smart cities scenario under consideration. Operator companies such as Verizon also explained their perspective on 5G and indicated their intention to start early trials and service rollouts of the technology in the next 3-5 years. The talk by GM was on emerging vehicle-to-vehicle (V2V) and vehicle-to-Infrastructure (V2I) applications using a combination of DSRC/802.11p and emerging 5G technologies. Vehicular applications driven initially by safety and information applications are expected to grow rapidly, evolving towards new autonomous vehicle applications which may place greater demands on network bandwidth and latency.

3.8 References:

Additional information about the workshop including submitted white papers, agenda, participant list and talk slides can be found at: www.winlab.rutgers.edu/events/wicities/