Appendix J:
VdM WiFi Network Planning

Contents

Abstract

In this Appendix, we investigate the scalability of Smart City IoT infrastructure and demonstrate the issues expected when expanding deployment to city-wide scale. Specifically, we focus on the number of cameras and access points, and bandwidth requirements for supporting a Smart City wireless video surveillance network using 802.11n and 802.11acbased technologies. We apply various common camera and gateway deployment patterns to demonstrate possible variations in Smart City deployment constraints and estimate the number of devices and resources required in 3 different scenarios. The deployments are simulated using Atoll network planning software based on installation parameters and equipment models obtained from our practical small-scale deployment in the MSCPS.

1. Wireless Deployment for Smart City Video Surveillance Network

As mentioned in the main report, the installation locations of IoT surveillance cameras is crucial in order to be fully realize their utility. As such, placement of cameras takes priority over the networking mechanisms that facilitate video transmission to the fiber-optic backbone infrastructure. In other words, the location of the camera installation should not depend on its proximity to the closest fiber drop as in the main report. Wireless communication technologies enable cameras to be installed much farther from fiber drops, allowing for more flexibility in deployment and surveillance coverage over the target area. However, wireless connections are affected a number of issues that influences the scalability of a Smart City video surveillance setup, namely wireless throughput, signal coverage, and deployment patterns of cameras and fiber drops. The objective of this Appendix is to demonstrate how these issues manifest in different Smart City deployment scenarios and to provide a conceptual prediction based on our pilot deployment experience.

The transmission throughput in a wireless video surveillance system depends on wireless communication technologies, radio/antenna devices, and the network topology that those devices are deployed in. In terms of wireless standards, 802.11n is widely popular with many variety of devices and implementations that drive the cost of a Wi-Fi-based deployment down. However, it is expected that 802.11ac will be the go-to standard in the near future for Wi-Fi communication technologies with its far superior data rate, though higher cost for 802.11ac equipment may be a limiting factor.

The network topology of wireless devices facilitating the connection between cameras and gateways is a major consideration for wireless deployment of Smart City surveillance application. The main report demonstrated a few point-to-point and point-to-multipoint topologies with small number of cameras over relatively short distances to gateways. However, in a full-scale deployment with many cameras deployed in all directions around a gateway, point-to-point becomes much less economical due to the high number of radio devices as each camera installation requires two radios to establish a point-to-point wireless bridge. Thus, a point-to-multipoint deployment where an access point, equipped with an omni-directional antenna, can serve all cameras within the vicinity and greatly reduce the number and cost of radio devices necessary is more desirable. In addition, signal coverage can be extended to farther locations by use of single-hop or multi-hop *relay APs*, which are APs that are connected to gateway via a series of relay wireless bridges. Different from *base APs* which are installed directly at gateway location, relay APs can be placed anywhere to provide stronger signal for cameras that are in blind spots or outside range of other APs.

In the following sections, we demonstrate a number of wireless deployment scenarios in selected Montreal areas. We start with small areas with high number of public activities with only base APs, then expand to larger commercial district that require extended coverage via relay APs as we iteratively scale up to the whole city. We try to minimize the quantity of APs needed to support deployment scenarios in a large-scale Smart City video surveillance application as well as provide a sparse deployment pattern which may reduce cost in equipment. This can provide an estimation of the number of cameras and wireless devices necessary for a full-scale deployment. We will provide planning predictions for both 802.11n and 802.11ac-based wireless technologies to give a benchmark for a present deployment and a future deployment respectively.

2. Simulation Organization

2.1 Scenarios

There are many deployment scenarios when considering a wireless video surveillance application for a designated area, depending on numerous factors: the type of application and data to be monitored, camera deployment patterns, location of gateways, wireless technologies, etc. In this section, we focus on intersection monitoring where cameras are placed at numerous intersections and junctions in a target area to record their vehicular and pedestrian traffic activities. The two main camera deployment patterns that we want to investigate are *high-density* deployment and *low-density* pattern. In a high-density deployment pattern, a camera is installed at almost every intersection in the target area to provide near complete surveillance coverage of ongoing traffic, excluding some small crossroads where traffic activities are too infrequent to justify the cost. If two intersections are close enough to each other that one camera can reasonably monitor both, then a second camera does not have to be installed. In a low-density deployment pattern, only intersections with traffic light are monitored by cameras, reducing cost of installation and maintenance while still providing surveillance at major locations in the target area.

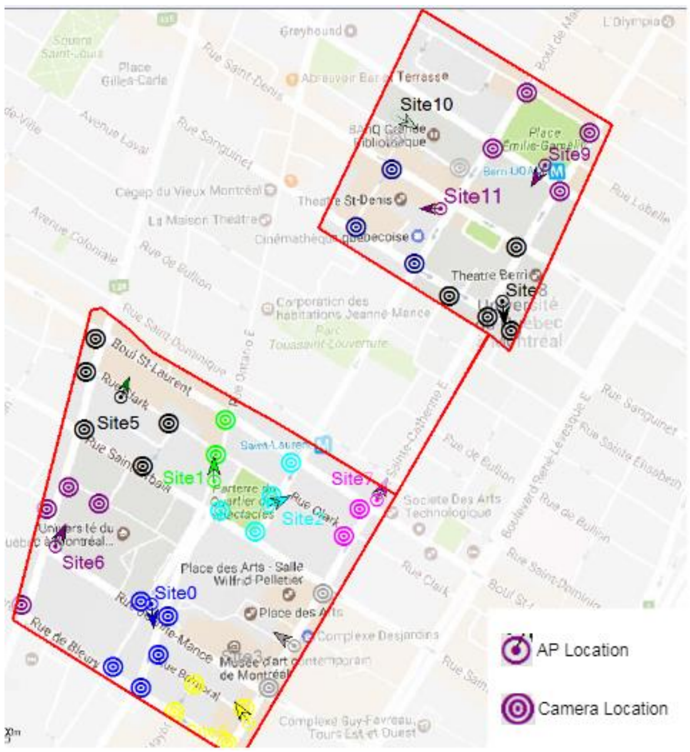

Figure 1: High-density camera deployment overview in two small areas of scenario 1.

Due to the sheer number of possible variations of high-density and low-density deployment patterns, scale of target areas, and distribution of gateways, as well as time limitations, we only apply one deployment scenario to each area of interest to cover as many cases as possible and gather a rough estimate for each scenario. First, we extend on the deployment in a small urban area done in this project, where the exact locations of gateways are well-established. In this Scenario 1, the target surveillance area is in Quartier des Spectacles, specifically the two areas around Place-des-Arts and Berri-UQAM Metro stations, where most public activities happen. The total area of the two regions amounts to approximately 0.36 km^2. Camera deployment follows the high-density pattern, where one camera is installed on a street light pole at every intersection, excluding small alleys and intersections already in field of vision of other cameras. Figure 1 gives an overview of the target area and the expected locations of the cameras. The wireless base APs are installed at the known gateway locations and are connected directly to the optical fiber network. With the small target area and the low number of cameras, wireless coverage is sufficiently provided by base APs at gateway locations that relay APs are not necessary. 802.11n-based wireless radios and APs are used to establish wireless network coverage in this scenario.

Next, we broaden the scope to the slightly larger commercial district area surrounding Quartier des Spectacles with a similar urban planning attributes (e.g., building types, traffic intersection density, etc.) to maintain the correlation with the previous scenario. In fact, the target area is the two larger surrounding regions that encompass the two areas around Place-des-Arts and Berri-UQAM Metro stations, respectively. As the gateway locations are not known for these larger areas, we assume that fiber drops are located along a major road through the target area. We consider two scenarios for the distribution pattern of gateway locations: Scenario 2 in which gateways are placed along a road near the edge of the target surveillance area, and Scenario 3 in which gateways are placed along a road going through the center of the target surveillance area. For Scenario 2, the gateways are located on Rue Amherst at the edge of the area, where most cameras are deployed toward one side of the road. In the other Scenario 3, the gateways are located on Rue de Bleury, with cameras distributed more evenly on both sides of the road. In both scenarios, while base APs are still installed directly at the gateway locations, single-hop relay APs are also used to extend coverage range to distant cameras in order to provide sufficient throughput. Each relay AP is connected to a gateway via a wireless bridge independent of the wireless network provided by the base APs installed at the corresponding gateway location.

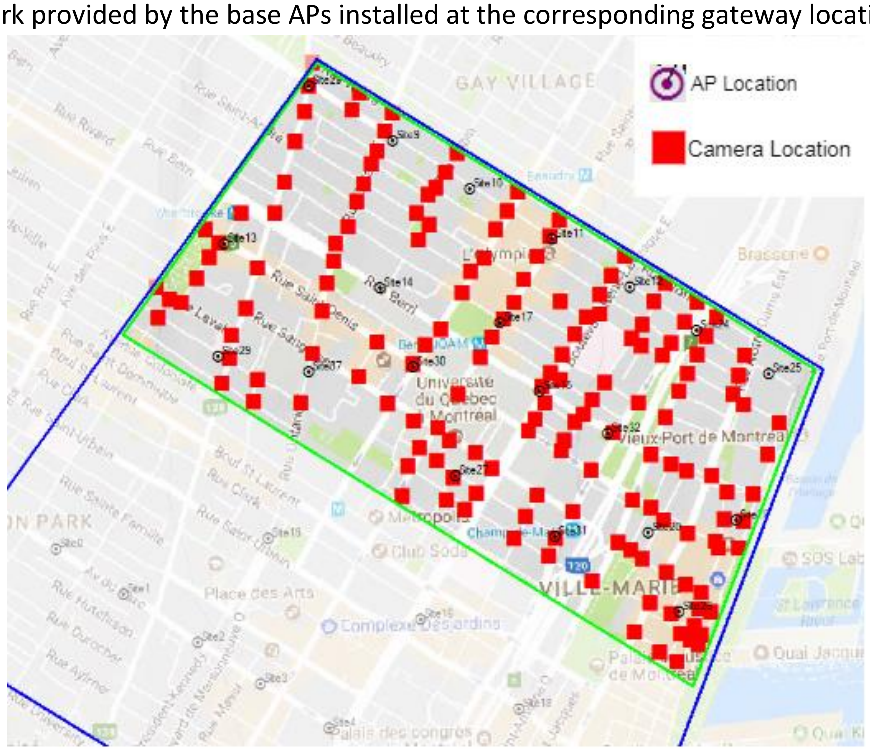

Figure 2: High-density camera deployment overview in scenario 2.

Figure 2 shows the overview of camera deployment pattern in Scenario 2 in the northeastern 1.6 km^2 half of the commercial district. Cameras are distributed following the high-density pattern, where a camera is installed at almost every intersection. In this scenario, base APs are installed at assumed gateway locations every 200 m along Rue Amherst near the northern edge of the target area. Thus, most cameras installations are located toward south of the base APs, so relay APs have to be distributed in regions that are out of range to provide coverage to all cameras. They are linked to base APs via point-to-point wireless bridges in the same manner described in the main report. The wireless network is setup using 802.11ac-based wireless radios and APs to contrast with the 802.11n deployment in scenario 1.

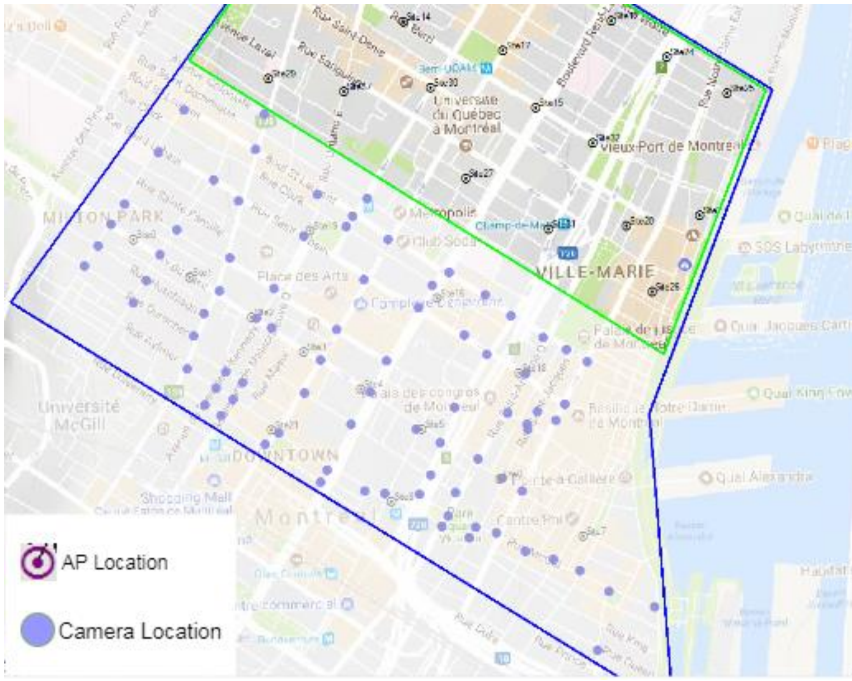

Figure 3: Low-density camera deployment overview in scenario 3.

Figure 3 depicts the overview of low-density pattern in Scenario 3 across the southern 2.1 km^2 half of the commercial district area, where cameras are only installed at intersections with traffic light. Similar to scenario 2, base APs are installed where the gateway locations are assumed to be along Rue de Bleury that goes through the center of the target area. There are still camera installations that are outside the range of base APs that require relay AP deployment, but they are more sparsely distributed as there are less cameras to be covered. The wireless network for this scenario is also based on 802.11ac-based wireless technologies and equipment as we look to contrast the deployment density in scenario 2.

2.2 System Parameters and Assumptions

Due to the constraints in equipment and time preventing a full physical deployment for empirical results, we choose to simulate the network performance of wireless video surveillance deployment based on the deployment data obtained in the MSCPS to maintain a realistic basis. In other words, the simulation models and parameters are based on the installation details and technical specification of camera equipment deployed. Similar to current installation, we assume that a wireless bridge radio and a camera are installed at the same location, attached 8 m above the ground on a light pole. This height is the standard height for light poles observed in the deployment area, and may not be applicable to other areas of Smart City. In terms of camera specification, the general network speed requirement for each camera is assumed to be 20 Mbps, which is the estimated average throughput to stream video data at UHD resolution while maintaining high quality footage, with some bandwidth margin to ensure smooth transmission.

Hardware and wireless protocol parameters

The hardware and wireless protocol parameters are based on the Ubiquiti Network's proprietary airMAX wireless technology and equipment, supported by device models in the directional wireless bridge radio NanoBeam and wireless access point Rocket series. Unlike standard Wi-Fi protocol, Ubiquiti's airMAX TDMA-based (Time-division Multiple Access) protocol allows each active station to send and receive data using pre-designated time slots scheduled by an intelligent associated AP, essentially eliminating the hidden node collisions typically encountered in large-scale Wi-Fi networks [1]. The AP also keeps track of airtime usage of each station to determine which stations are active, then reassigns available time slots so that airtime efficiency is maximized [1]. Thus, airMAX provides significant performance improvement in latency, throughput, and scalability in comparison to CSMA (Carrier Sense Multiple Access) protocol employed by traditional Wi-Fi standards.

Specifically, for the 802.11n-based Scenario 1, we use the NBE-M5-16 wireless bridge radios and the Rocket-M5 wireless access point, equipped with omni-directional antennas AMO-5G10, to represent stations (i.e., the cameras), and AP, respectively. The specifications of the devices are shown in Figure 4 and 5. Although the supposed maximum data rate supported by the Rocket-M5 AP is 130 Mbps at index MCS15 [2], according to 802.11n standard [3], it only has a 100 Mbps networking interface, meaning that each AP can only serve up to 5 stations simultaneously to ensure that every camera can transmit at maximum rate. A key consideration is that the AMO-5G10 antenna projects a narrow beam width of 12° on the horizontal elevation plane (as shown in Figure 4) [4], which means that wireless radios and APs have to be installed at similar height for maximum signal strength.

Similarly, for the 802.11ac-based Scenarios 2 and 3, we use the NBE-5AC-16 wireless bridge radios and the R5AC-Lite wireless access point, also equipped with AMO-5G10 antennas, to represent the stations and the AP, respectively. Figure 6 and 7 shows the specifications of the station and the AP devices. The R5AC-Lite AP includes a 1000 Mbps LAN networking interface, allowing it to support fully the maximum

NBE-M5-16 (Station)
Specifications

TX Power	-4 to 26 dBm
Operating Frequency	5150 to 5875 MHz
Antenna gain	Directional 16 dBi
Half-power Beamwidth	27 degree
Channel Sizes	5/8/10/20/30/40 MHz
Supported standard	802.11a/802.11n airMAX
MIMO configuration	2x2
Ports	10/100 Mbps Ethernet

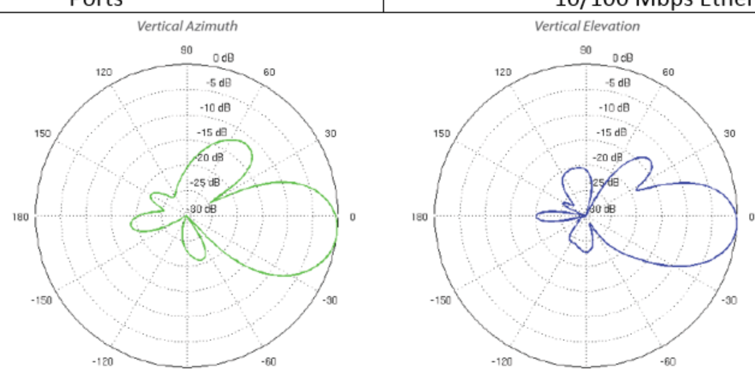

Figure 4: NBE-M5-16 Specifications and Antenna Pattern

data rate of 360 Mbps at index MCS9 of 802.11ac standard [5], [6]. Thus in 802.11ac-based scenarios, each AP can easily serve up to 13 stations simultaneously if we allow some bandwidth space as margin.

ROCKET-M5 (AP) with antenna AMO-5G10
Specifications

TX Power	-4 to 26 dBm
Operating Frequency	5150 to 5875 MHz
Antenna gain	Oimi-10 dBi
Channel Sizes	5/8/10/20/30/40 MHz
Supported standard	802.11a/802.11n airMAX
MIMO configuration	2x2
Ports	10/100 Mbps Ethernet

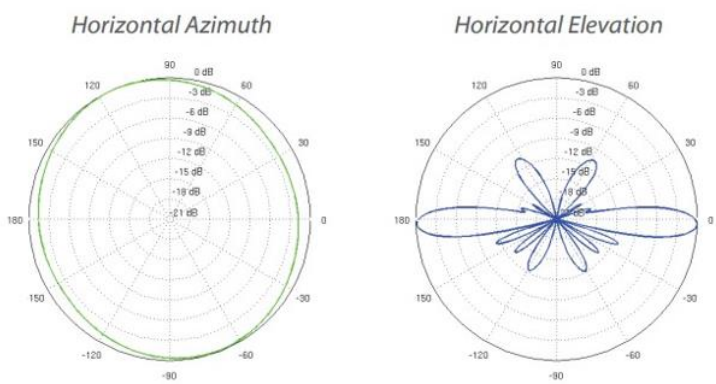

Figure 5: ROCKET-M5 Specifications and AMO-5G10 Antenna Pattern.

Ubiquiti NBE-5AC-16 (Station)
Specifications

TX Power	-4 to +26 dBm
Operating Frequency	5150 to 5875 MHz
Antenna gain	Directional 16 dBi
Half-power Beamwidth	27 degree
Channel Sizes	5/8/10/20/30/40 MHz
Supported standard	802.11ac airMAX-TDMA
MIMO configuration	2x2
Ports	100/1000 Mbps Ethernet

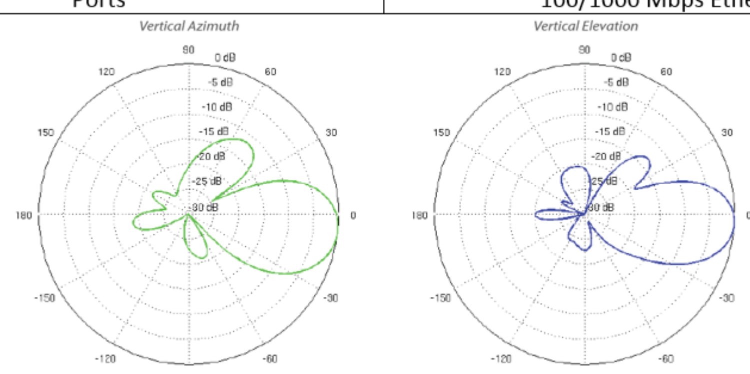

Figure 6: NBE-5AC-16 Specifications and Antenna Pattern.

Ubiquiti R5AC-Lite with antenna AMO-5G10 (Access Point)
Specifications

TX Power	-4 to 26 dBm
Operating Frequency	5150 to 5875 MHz
Antenna gain	Omni 10 dBi
Channel Sizes	5/8/10/20/30/40 MHz
Supported standard	802.11ac airMAX
MIMO configuration	2x2
Ports	100/1000 Mbps Ethernet

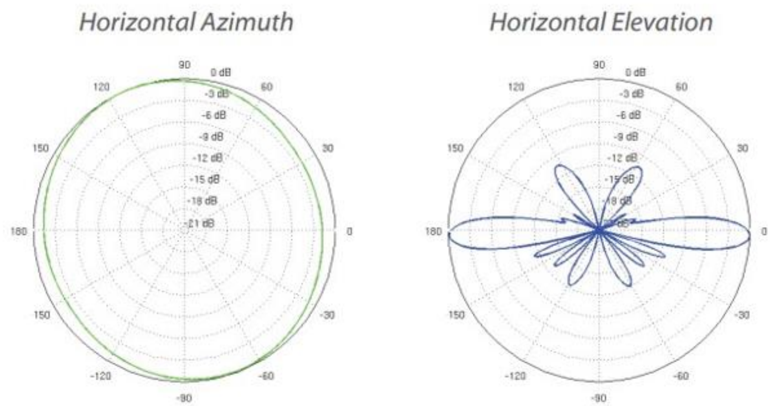

Figure 7: R5AC-Lite Specifications and AMO-5G10 Antenna Pattern

We assume the transmit (TX) power of the antenna to be at the minimum -4 dBm, and the noise figure between stations and APs to be 5 dB, which is observed in performance of similar radios. Finally, the installation height of all devices is assumed to be the same as the physical deployment at 8 m for maximum signal strength. The height difference tolerance is 10 m at the maximum theoretical distance from the AP, which is 500 m in order to still satisfy the throughput requirement at -4 dBm TX power. In other words, at similar installation height, the terrain elevation difference could be tolerated up to 10 m without significant signal degradation.

Simulation software and propagation model

Many radio-frequency network planning tools can be used to simulate wireless deployment scenarios, such as ATDI's ICS telecom EV, Forsk's Atoll, iBwave, etc. Numerous telecommunications companies also offer network planning services, such as Cisco, Nokia, and Aerohive. Our simulation is performed using Atoll [82], a comprehensive radio planning and optimization platform that can provide wireless coverage analysis, downlink and uplink throughput estimations, and automatic channel allocation and frequency planning. Developed by Forsk, Atoll offers an extensive integrated propagation model library, supporting many types of radio technologies and equipment, including Ubiquiti 802.11n/ac-based wireless devices as well as the proprietary airMAX protocol.

To simulate the wireless environment, Atoll provides multiple propagation models to be used for network coverage predication, as summarized in Table J.1. We use the Erceg-Greenstein (SUI) [7] propagation model as it is the most suited for in the 1.9 to 6 GHz frequency range over distances between 100 m and 8 km of urban or sub-urban areas, which is similar to our target deployment environment. A digital terrain model (DTM) is used to represent the ground-level elevation above sea level in our propagation model, though due to financial constraints, we can only obtain model at 30-meter resolution (i.e., 1 pixel represents a 30m-by-30m area) without any clutter land-use information (e.g., buildings, vegetation) that may impact radio wave propagation. Under such restrictions, the model does not include clutter classes, data describing the land use on the terrain (e.g., buildings) which can impact radio propagation due to their physical and electrical properties, and clutter heights, data representing height of buildings, structures, and vegetation features in the area. Thus, the simulation assumes no radio interference from buildings and other on-site devices (i.e., public or private Wi-Fi networks deployed by third party).

Table 1: Summary of Propagation Models provided by Atoll.

Model	Frequency Range	Geo Data Taken into Account	Recommended Use
Cost-Hata (Automatic calibration)	1500 – 2000 MHz	Terrain profile Statistical clutter (at the receiver)	1 < d < 20 km GSM 1800, UMTS, CDMA2000, LTE
ITU 529-3	300 – 1500 MHz	Terrain profile Statistical clutter (at the receiver)	1 < d < 100 km GSM 900, CDMA2000, LTE
Standard Propagation Model (Automatic calibration)	150 – 3500 MHz	Terrain profile Statistical clutter	1 < d < 20 km GSM, UMTS, CDMA2000, LTE, WiMAX, Wi-Fi
Erceg-Greenstein (SUI)	1900 – 6000 MHz	Terrain profile Statistical clutter (at the receiver)	Urban and suburban areas 100 m < d < 8 km Fixed WiMAX, Wi-Fi
Sakagami Extended (Automatic calibration)	3000 – 8000 MHz	Terrain profile Statistical clutter	1 < d < 20 km LTE, WiMAX, Wi-Fi
3GPP 38.900 (Automatic calibration)	6 – 100 GHz	Terrain profile Statistical clutter	1 < d < 10 km
CrossWave Model	200 – 5000 MHz	Terrain profile Statistical or deterministic clutter 3D building and line vectors (optional) Specific morphology, facets and graphs data files (optional)	All types of environments Small, micro, and macro cells GSM, UMTS, CDMA2000, LTE, WiMAX, Wi-Fi
Aster Propagation Model (Automatic calibration)	150 – 5000 MHz	Terrain profile Statistical or deterministic clutter 3D building and line vectors (optional)	All types of environments, particularly dense urban areas with high resolution raster data Small, micro, and macro cells GSM, UMTS, CDMA2000, LTE, WiMAX, Wi-Fi

The AP configuration is modelled as transmitter in Atoll. Its properties are set as shown in Figure 8.

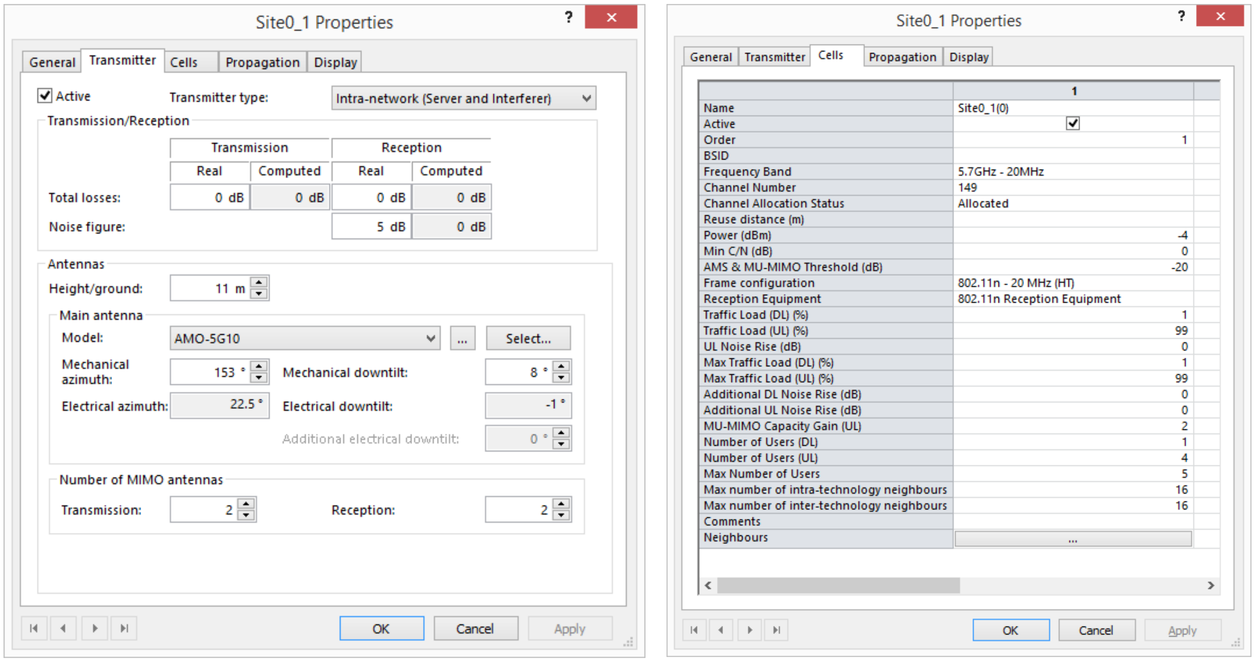

Figure 8: AP Properties in Atoll Settings

3. Simulation Results and Discussion

3.1 Scenario 1: High-density 802.11n-based deployment

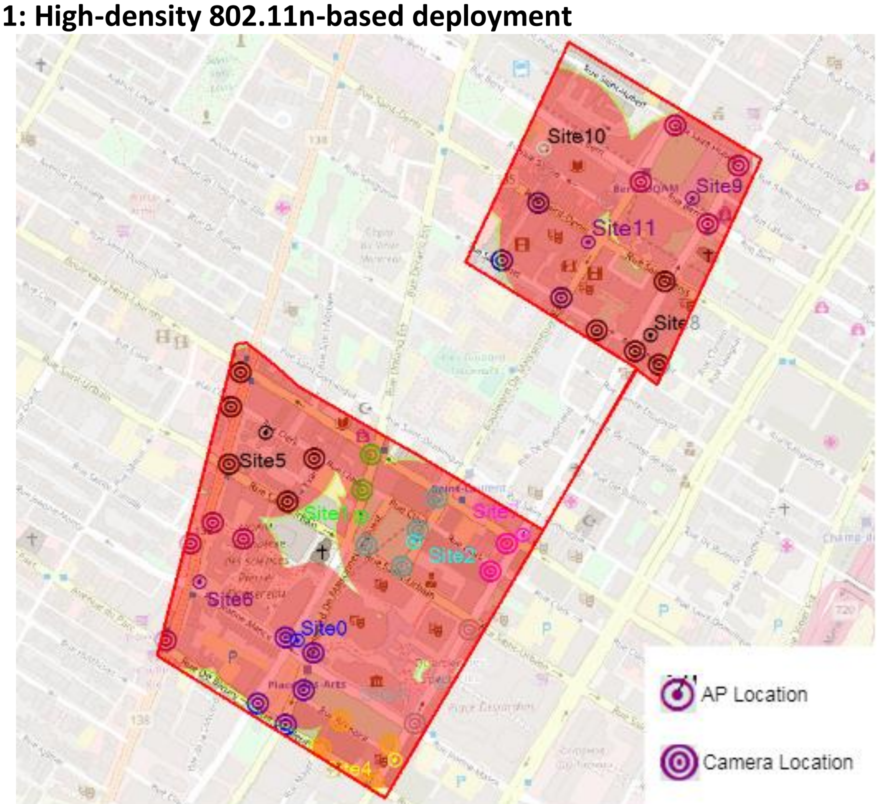

Figure 9: Signal strength coverage of 802.11n-based wireless networks in Scenario 1

In Scenario 1, it is shown in Figure 5 that we can provide high throughput coverage to every station/camera in the target surveillance areas given our constraints. In total, there are 12 APs covering 41 cameras across the two areas, with every camera capable of reaching peak data rate of up to 150 Mbps. The camera and AP densities for 802.11n based deployment in this scenario are 113 cameras/km^2 and 33 APs/km^2, respectively. The wireless networks by these APs are automatically allocated to 3 different channels by Atoll AFP module to avoid interference between non-overlapping cells, specifically channels 149, 157, and 165. Table 2 shows the channel allocation of each AP cell.

Table 2: Scenario 1 Automatic Channel Allocation

	Site	Transmitter	Name	Frequency Band	Initial Channel Number	Channel Number	Channel Allocation Status	Cost
	Site0	Site0_1	Site0_1(0)	5.7GHz - 20MHz	149		Allocated	-
	Site1	Site1_1	Site1_1(0)	5.7GHz - 20MHz	157		Allocated	-
	Site10	Site10_1	Site10_1(	5.7GHz - 20MHz	149		Allocated	-
	Site11	Site11_1	Site11_1(	5.7GHz - 20MHz	157		Allocated	-
	Site2	Site2_1	Site2_1(0)	5.7GHz - 20MHz	165		Allocated	-
	Site3	Site3_1	Site3_1(0)	5.7GHz - 20MHz	157		Allocated	-
	Site4	Site4_1	Site4_1(0)	5.7GHz - 20MHz	165		Allocated	-
	Site5	Site5_1	Site5_1(0)	5.7GHz - 20MHz	149		Allocated	-
	Site6	Site6_1	Site6_1(0)	5.7GHz - 20MHz	165		Allocated	-
	Site7	Site7_1	Site7_1(0)	5.7GHz - 20MHz	149		Allocated	-
	Site8	Site8_1	Site8_1(0)	5.7GHz - 20MHz	149		Allocated	-
	Site9	Site9_1	Site9_1(0)	5.7GHz - 20MHz	165		Allocated	-

As reference for deployment purposes, it should be noted that the average distance between a camera and an AP is 80 m, with the maximum distance at 150 m. Both distances are well within the maximum throughput coverage area of an AP. Table 3 summarizes the results of this deployment scenario. However, this result is very optimistic as the simulation model does not account for interference and obstacles to radio propagation.

Table 3: Scenario 1 Result Summary

Area	# of Cameras # of APs	Camera Density AP Density	Average distance between AP and camera	Maximum distance between AP and camera	Total bandwidth required
0.36 km^2	41 12	113 cameras/km^2 33 APs/km^2	80 m	150 m	0.8 Gbps

3.2 Scenario 2: High-density 802.11ac-based deployment

In this high-density deployment displayed in Figure 6, we are able to provide more complete coverage of the entire northern commercial district with the use of relay APs, allowing every camera to achieve maximum throughput available even with suboptimal locations of the gateways. The wireless bridges between relay APs and gateways are spread out evenly across the available gateways such that each gateway serves no more than 2 relay APs, as the high traffic each relay AP delivers can overload the gateway. In total, 7 base APs and 13 relay APs are deployed to cover 161 cameras in this larger 1.6 km^2 region, thus the camera and AP densities for this high-density deployment scenarios are 100 cameras/km^2 and 13 APs/km^2, respectively.

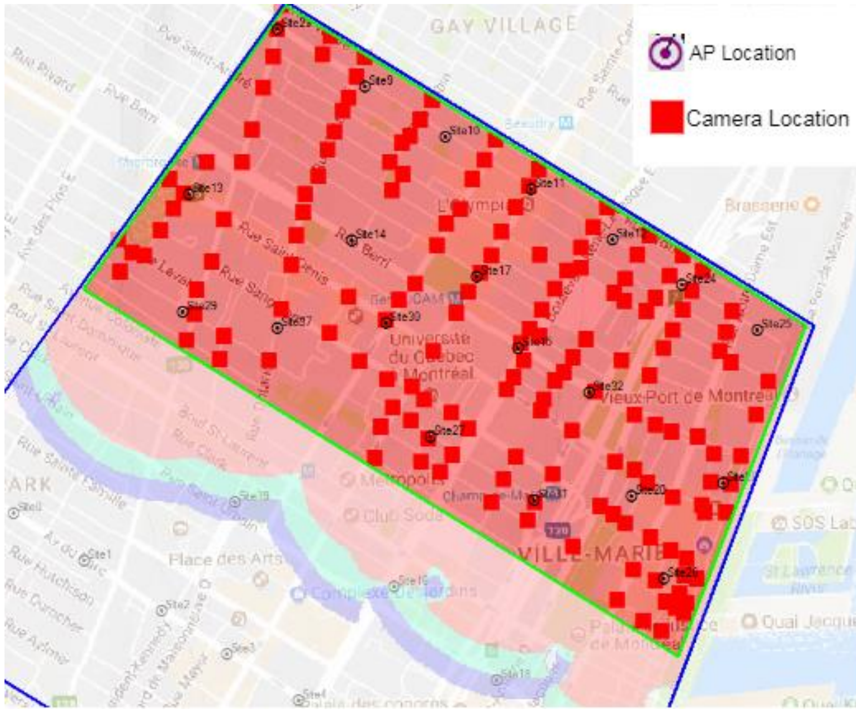

Figure 10: Signal strength coverage of high-density 802.11ac-based wireless networks in Scenario 2

Compared to Scenario 1, the camera deployment density of Scenario 2 is very similar with 13% margin. This result provides an approximate basis to estimate the number of APs needed to support a high-density deployment using 802.11n and 802.11ac-based implementations. The density of 802.11n-based APs is much higher than 802.11ac-based deployments (33 APs/km^2 vs 13 APs/km^2, respectively), which is expected as 802.11n supports significantly lower data rate and thus few number of cameras per AP than 802.11ac. This difference in AP density nullifies any cost advantage that 802.11n-based deployment has due to cheaper device cost, meaning that for a large-scale deployment, 802.11ac is better both in terms of cost and minimizing device quantity.

It should be noted that in this simulation scenario 2, the average distance between AP and camera is about, and the maximum distance is 243 m. Given the assumption that base APs are deployed at fiber drops near the edge of the target area, the average distance between a relay AP and a base AP is 450 m, with the maximum distance at 723 m. Table 4 summarizes the results of this deployment scenario.

Table 4: Scenario 2 Result Summary

Area	# of Cameras # of APs	Camera Density AP Density	Average distance - between AP and camera - between relay AP and base AP	Maximum distance - between AP and camera - between relay AP and base AP	Total bandwidth required
1.6 km^2	161 21	100 cameras/km^2 13 APs/km^2	148 m 450 m	243 m 723 m	3.2 Gbps

3.3 Scenario 3: Low-density 802.11ac-based deployment

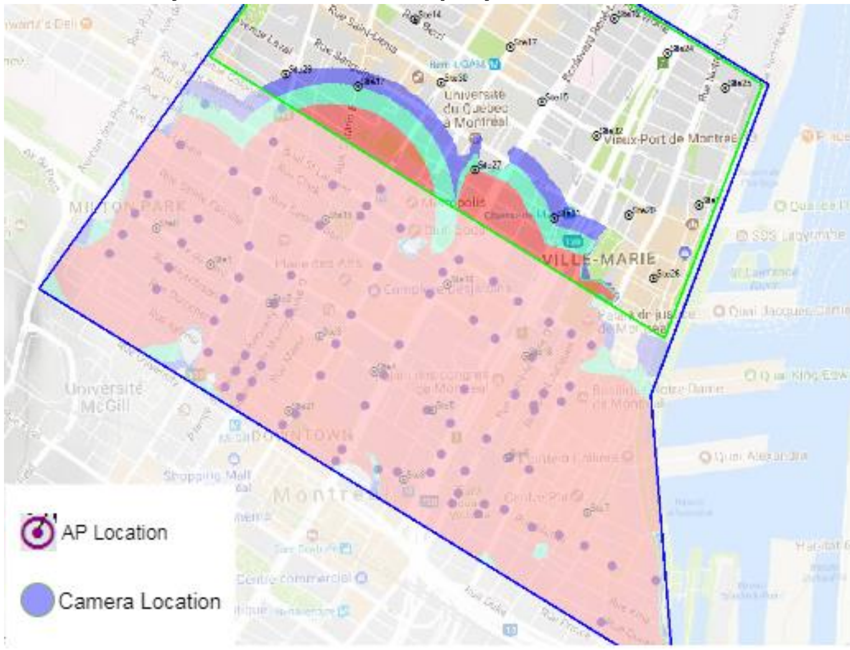

Figure 11: Signal strength coverage of low-density 802.11ac-based wireless networks in Scenario 3

In the low-density deployment shown in Figure 7, most cameras are covered by the base APs at gateway locations along the central street, thus fewer wireless bridges and relay APs are needed to extend coverage over the entire area. Relay APs are placed more sparsely throughout to maximize the number of stations that each AP supports, with only 14 APs are used to cover 85 cameras in the 2.1 km^2 target area, which amounts to 40 cameras/km^2 and 7 APs/km^2 in camera and AP densities respectively. As a result, a few cameras are outside the maximum throughput coverage, though they can still achieve acceptable data rate that we consider it unnecessary to deploy additional relay APs for them. It should be noted that the uneven terrain, according to our DTM, and the narrow horizontal beam width of the omni-directional antennas result in irregular coverage patterns and occasional blind spots where wireless signal is not strong enough.

In comparison to Scenario 2, the low-density deployment in Scenario 3 employs fewer number of cameras and APs, which scales down the throughput load on the network infrastructure and cost of deployment, making it a more viable solution for areas with limited financial and networking resources. Low-density deployment reduces bandwidth requirement by 60%, requiring only 40 cameras/km^2 as opposed to 100 cameras/km^2 in Scenario 2. Also, less APs are required to provide sufficient coverage and throughput support for the cameras, at approximately 7 APs/km^2. If we correlate the ratio between high-density and low-density to 802.11n-based deployment, we would still need 18 APs/km^2, which is even more devices than high-density 802.11ac-based deployment.

It should be noted that in this scenario, the average distance between AP and camera is 204 m, and the maximum distance is 457 m, both are longer than those of Scenario 2 due to the sparser deployment. On the other hand, the average distance between relay AP and base AP is only 399 m, with the maximum distance at 453 m. These values are less than those of Scenario 2 as the base APs are located through the center of the target area, which significantly reduces the distance from base APs to relay APs. Table 4 summarizes the results of this deployment scenario.

Table 4: Scenario 3 Result Summary

Area	# of Cameras # of APs	Camera Density AP Density	Average distance - between AP and camera - between relay AP and base AP	Maximum distance - between AP and camera - between relay AP and base AP	Total bandwidth required
2.1 km^2	85 14	40 cameras/km^2 7 APs/km^2	204 m 399 m	457 m 453 m	1.66 Gbps

3.4 Scale-up estimation

Based on these preliminary results, we can make estimations on the number of cameras and APs, and bandwidth required to deploy over larger areas. For example, the downtown Montreal and Quartier de l'innovation region, which has about 9 km^2 in area as shown in Figure 8, has similar urban features and intersection distribution as the areas in our test scenarios. Based on Scenario 1 results, we would need about 1005 cameras and 293 APs for a high-density 802.11n-based deployment, supporting roughly 20 Gbps total throughput. Similarly, high-density 802.11ac-based deployment would utilize about 900 cameras and 117 APs, according to estimations of Scenario 2, which requires 18 Gbps in throughput. Finally, low-density 802.11ac-based deployment, with 360 cameras and 63 Aps, would require 7.2 Gbps to support data transmission. Scaling up to high-density deployment covering the whole island of Montreal (almost 506 km^2), we would need roughly 50000 cameras, 6000 APs, and 1 Tbps throughput. For context, most fiber-optic networks can only support up to 10 Gbps, and are often clustered with other types of Internet traffic. It is noted that these are very rough estimations as the actual numbers may differ due to variations in intersection and gateway densities in target deployment areas.

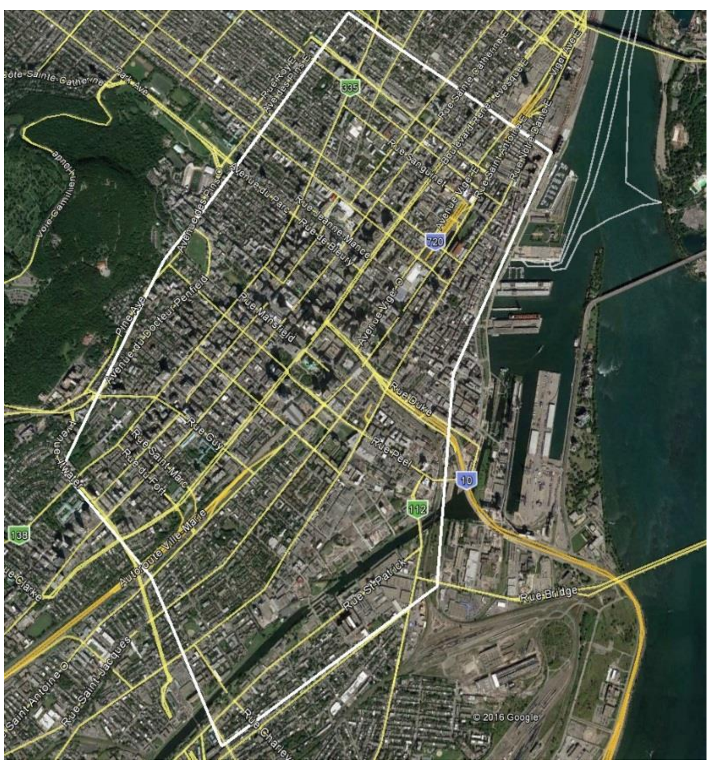

Figure 12: Downtown and Quartier de l'Innovation area overview.

While these estimates are preliminary, the huge throughput requirements raise nontrivial questions about how much resources in a given area can Smart City support and how to distribute networking resources to numerous devices and applications. One thing is for certain: a centralized network infrastructure and data management system will not be able to scale with the demand of Smart City. Thus, designing a scalable distributed IoT infrastructure is crucial to enable a full-scale Smart City deployment for demanding applications such as video surveillance network. Table 5 summarizes the prediction for the scaled deployment in both low density and high density deployment patterns.

Table 5: Scale-up estimation summary for Downtown and Quartier de l'Innovation à Montréal (9 km^2)

Deployment patterns	Camera Density AP Density	Predicted # of Cameras Predicted # of APs	Predicted total bandwidth required
802.11n-based high density	113 Cameras/km^2 33 APs/km^2	~1,000 cameras ~293 APs	20 Gbps
802.11ac-based high density	100 Cameras/km^2 13 APs/km^2	~900 camera ~117 APs	18 Gbps
802.11ac-based low density	40 Cameras/km^2 7 APs/km^2	~360 cameras ~63 APs	7.2 Gbps

4. Concluding Remarks

We have simulated various scale-up deployment scenarios of Smart City wireless video surveillance network to demonstrate the scalability issues to be expected for a full-scale IoT deployment. Based on the experimental setup done in the MSCPS, we extend deployment to cover larger areas with two 802.11-based wireless technologies (802.11n and 802.11ac) in high-density and low-density camera deployment patterns. The simulations produce preliminary estimations about the required quantity of devices and network resources to support large-scale scenarios, indicating that 802.11ac-based deployments are more cost efficient and require few devices to be deployed by 60% when compared to 802.11n-based deployments. The results also indicate that to provide citywide coverage, we would need as many as 50000 cameras and 6000 APs, which require 1 Tbps of bandwidth to support high-quality video streaming demand. The IoT network infrastructure of Smart City must be carefully designed to be capable of scaling with this huge amount of data traffic.

References

[1] *AirMAX TDMA System*. Ubiquiti Networks. 2014.

[2] *Rocket M: Powerful 2x2 MIMO airMAX BaseStation*. Ubiquiti Networks. 2015.

[3] "IEEE Standard for Information technology– Local and metropolitan area networks– Specific requirements– Part 11: Wireless LAN Medium Access Control (MAC)and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput". In: *IEEE Std 802.11n-2009 (Amendment to IEEE Std 802.11-2007 as amended by IEEE Std 802.11k-2008, IEEE Std 802.11r-2008, IEEE Std 802.11y-2008, and IEEE Std 802.11w-2009)* (2009).

[4] *airMAX Omni: Next-Gen 2x2 Dual Polarity MIMO Omni Antenna*. Ubiquiti Networks. 2012.

[5] "IEEE Standard for Information technology–Telecommunications and information exchange between systemsLocal and metropolitan area networks–Specific requirements– Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications–Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz". In: *IEEE Std 802.11ac-2013 (Amendment to IEEE STd 802.11-2012, as amended by IEEE Std 802.11ae-2012, IEEE Std 802.11aa-2012, and IEEE Std 802.11ad-2012)* (2013).

[6] *Rocket ac: Powerful airMAX ac BaseStation*. Ubiquiti Networks. 2015.

[7] V. Erceg, L. Greenstein, S. Tjandra, S. Parkoff, A. Gupta, et al. "An empirically based path loss model for wireless channels in suburban environments". In: *IEEE Journal on Selected Areas in Communications* 17.7 (1999), pp. 1205–1211.