# Wi4Net White Paper:

## *Citywide Wireless Video Surveillance –*
## *How to design a network the right way!*

Designing a Citywide Wireless Surveillance System – “the right way” – is a highly complex task, underestimated by many. If one would believe the propaganda of some mesh radio node vendors, it is just a matter of putting up mesh radios at each street corner, and your backbone infrastructure is complete. Just add cameras were you like. However, most mesh radio solutions have been designed for municipal Wi-Fi projects where cost-effective coverage has been the main objective with “as-is” data rates. Also, Internet traffic is fundamentally different from the data traffic, characteristic for a video surveillance application. In a typical Internet application, the traffic is “bursty” in nature, meaning only periodic bursts of data are sent or received, for example only when the user sends an e-mail or requests a web-site page. Also, data rates in the range of 500 kbps and 1 Mbps will provide for a “broadband” user experience that is still satisfactory to most users today (and higher data rates can rarely be expected in a traditional Wi-Fi mesh network).

### Video as “Killer Application”

Video, specifically as it is implemented in a video surveillance application, truly is a killer application. Each camera feeds high bandwidth streams of data on a continuous basis. When high motion is encountered, at 30 Frames Per Second (FPS) and 4CIF resolution, a single video stream requires as much as 4 Mbps (using MPEG-4 encoding) (see table below).

**MPEG-4 Video Bit Rate Estimates (High Motion)** Bit Rate = kb/s

(Frame Per Second - FPS)

| Resolution | 1 | 2 | 4 | 5 - 7 | 6 - 8 | 10 | 15 | 30 |
|---|---|---|---|---|---|---|---|---|
| QCIF (176x144) | 8 | 17 | 34 | 51 | 68 | 84 | 127 | 253 |
| CIF (352x288) | 34 | 68 | 135 | 203 | 270 | 338 | 507 | 1014 |
| 2CIF (704x288) | 68 | 135 | 270 | 406 | 541 | 676 | 1014 | 2028 |
| 4CIF(704x576) | 135 | 270 | 541 | 811 | 1081 | 1352 | 2028 | 4055 |

CIF- Common Intermediate Format

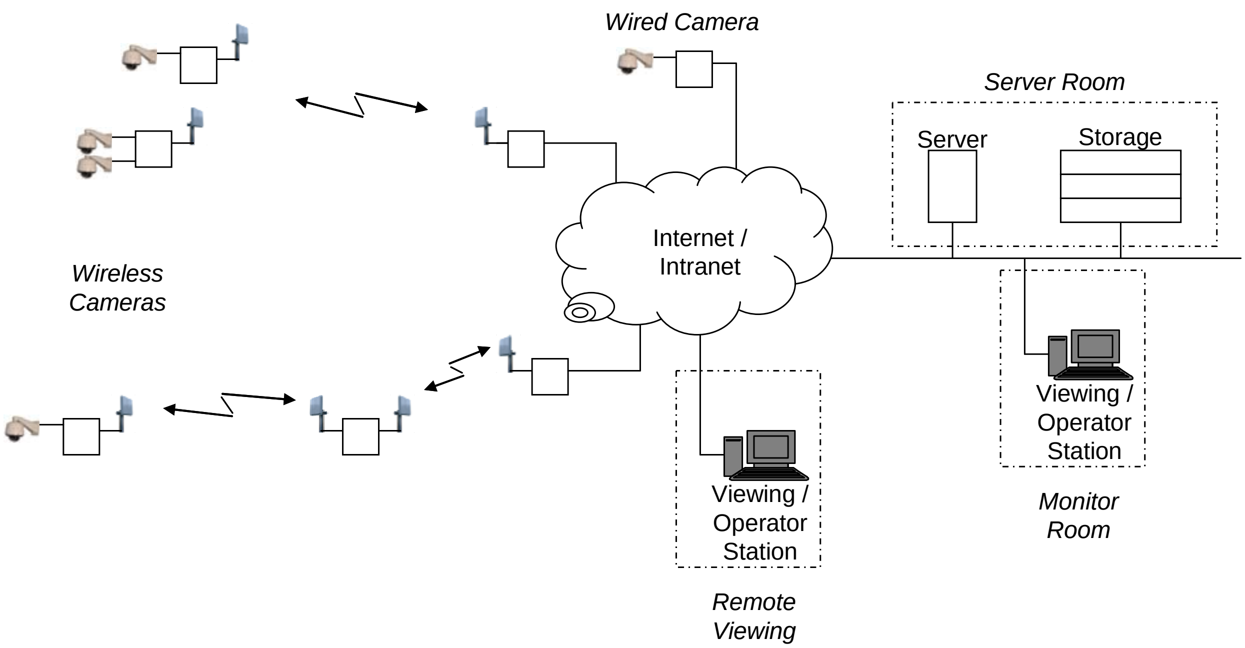
The key challenge in designing a citywide video surveillance system is to design the backhaul network in such a way that each camera can stream its video in a reliable, predictable fashion, in line with a frame rate and resolution that meets the customer’s expectations.

This document discusses the components of a citywide surveillance system, and the steps to follow from concept to models for sustained operation.

## System Components

The core components of an IP-based citywide surveillance network are ***(1) the camera / encoder units*** (with or without wireless capability), ***(2) the backhaul infrastructure*** (wireless and / or fiber) and ***(3) the back-end solution*** (including server, storage, management software solution, and monitoring facility). The following diagram shows a schematic of a complete network with all above components.




## Backhaul Design

As indicated on the previous page, a crucial element of a properly designed citywide surveillance network is a properly dimensioned backhaul network that provides for reliable and predictable data rates for each camera. When available, fiber backhaul typically provides for data rates of 100 Mbps or more; thus more than sufficient for most implementations, and certainly ideal. However, fiber backhaul often is not available or, at best, only few locations have access to fiber. The costs for building out a city-owned fiber network are generally not realistic. Alternatively, a local service provider will typically be able to provide high speed fiber connections to requested locations at a monthly fee, but the costs of operating the surveillance network usually become prohibitive in this scenario.

Therefore, in most citywide surveillance systems, wireless technology enables a municipality to build out the system at an affordable cost point. However, if the wireless part of the network is not properly designed, the customer will be disappointed with the performance of the network.

First, with regards to spectrum choice, the 4.9 GHz public safety spectrum is strongly recommended as the primary band to avoid interference and maximize performance. The band is available at no charge to municipalities, and, in most instances, is still highly underutilized. In the 4.9 GHz band, a total of 50 MHz is available. With a typical channel size of 10 MHz, 5 channels are available, and frequency re-use is fairly easy to implement. When each radio link is properly designed and optimized, typical sustained throughput per 10 MHz channel is in the range of 8 to 16 Mbps. The City of Long Beach has deployed one of the first and largest wireless surveillance systems in the country. With the current design supporting 59 cameras to stream video simultaneously to one aggregation point solely using the 4.9 GHz, this implementation is evidence of the capabilities of the 4.9 GHz band.

It is recommended to design the backhaul network conservatively, with sufficient margins to account for real life performance fluctuations in the wireless links. Therefore, “high motion” (maximum) data rates should be assumed for each stream in the traffic calculations. Also, future expansion plans should be considered in designing the backhaul network.

**Single Radio, Dual Radio or Multi-radio Wireless System**

Multi-radio solutions are strongly recommended for the implementation of a wireless video surveillance system, compared to architectures using single or dual radio systems. Single and dual mesh radio solutions offer a cost-effective solution for dense networks to provide for coverage (as required for municipal Wi-Fi projects), but these systems have not been designed for high throughput applications with a high level of predictability.

Multi-radio systems (such as the solutions from Wi4Net and others) can be configured using directional antennas with dedicated radios in each direction, ensuring the highest possible throughput in each link. Also, the use of directional antennas reduces self-interference and facilitates the implementation of frequency re-use within the network. Single and dual radio solutions require use of omni directional antennas, reducing link budgets and throughput while increasing self-interference throughout the network. Most importantly, with a single or dual radio implementation, one radio is required to take data from one direction and relay it into another direction, theoretically reducing the throughput by as much as 50%. Moreover, because real-life implementation are typically more complex (with more than just two directions) and the occurrence of collisions, much further reductions in throughput should be expected. By contrast, a properly designed multi-radio backhaul network should present a predictable throughput of 8 to 16 Mbps is every wireless link (assuming 10 MHz channels).

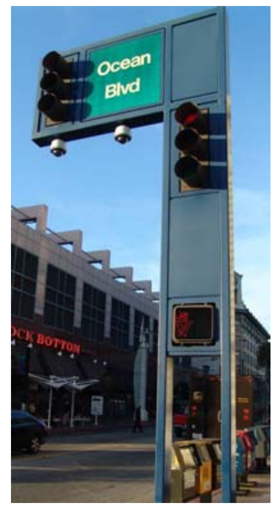
*Radio Reference Specifications*

| | |
|---|---|
| **Spectrum** | 4.9 GHz, with flexibility for other bands |
| **Bandwidth** | 5, 10, 20 or 40 MHz |
| **Design** | PTP, PMP or dynamic mesh |
| **Architecture** | Multi-radio (scalable to 4 or more) |

## Cameras

Cameras that typically suit citywide surveillance applications are PTZ cameras, i.e. cameras that allow for pan, tilt and zoom control. These cameras allow for capturing video images from different view points, without the need for multiple cameras at a single location, and, with their zoom capabilities, provide high resolution images at great distances, such as readable license plates at several hundred meters from the camera (assuming 35X optical zoom). In citywide surveillance systems, controlling all cameras individually all the time is logistically not realistic. Therefore, PTZ cameras can be programmed to perform a “tour” or “pattern”, whereby the camera is programmed to move automatically in a loop passed various predefined locations or areas of interest. When necessary, the operator can override the automatic tour mode, and manually move the camera.




Citywide surveillance systems require high performance PTZ cameras with some specific capabilities. For example, low light sensitivity is important to assure performance at night. A “day/night” camera is a requirement, with the capability to switch to a “black & white” mode automatically in case sufficient light exposure is not available to support quality color images. A camera with a high dynamic range is important to distinguish activity in shaded (darker) areas when neighboring areas are exposed to abundant sunshine. A window blanking feature makes it possible to mark areas that are blocked from viewing, such as windows of residential buildings.

*Camera Reference Specifications*

| | |
|---|---|
| **Type** | PTZ; suitable for continuous touring |
| **Pan Range** | Endless (360 degrees) |
| **Optical Zoom** | 35X |
| **Dynamic Range** | 128X |
| **Low Light Sensitivity** | 0.063 lux at 1/4 sec color & 0.00018 lux at 1/2 sec B&W |
| **Features** | Window blanking |

## Encoding

Various encoding protocols are available in the industry. MPEG-4 is recommended as the encoding scheme of choice. MPEG-4 encoding is mature and widely implemented within cameras, encoders and management solutions. M-JPEG is also widely available, but demands about three times the bandwidth required with MPEG-4. H.264 shows promise as an emerging encoding scheme, but vendor support is limited at this moment, and the increased processing requirement is a disadvantage.

The use of a dual stream encoder provides advantages. A dual stream encoder allows the user to configure two independent video streams with user-definable frame rates and resolutions. The advantage is that this allows for viewing and recording at different rates and resolution, and provides added flexibility to the system. Note that both streams should be utilizing MPEG-4 encoding. Many dual stream encoders only support one MPEG-4 stream, while the second stream uses M-JPEG encoding. This implementation is not useful for citywide wireless surveillance systems, since M-JPEG requires too much bandwidth.

*Encoder Reference Specifications*

| | |
|---|---|
| **Encoding Scheme** | MPEG-4 |
| **Type** | Dual stream (each based on MPEG-4) |
| **Frame rate** | Up to 30 FPS (for each stream) |
| **Resolution** | Up to 4CIF (for each stream) |

**Digital Video Management System**

A key component in the overall solution is a software package, generally referred to as Digital Video Management System (or “DVMS”), that essentially manages the entire surveillance system. A professional DVMS allows for central configuration of the cameras and encoders, manages the video streams (routing the streams to the storage system and viewing stations), and implements hierarchical access control (with different rights for different user groups and users).

Current solutions are fully digital. Due to high computing demands, all professional packages will use a server for basic system management functions and video stream control, and separate machines for viewing functions.

Typically, various software modules are available within the DVMS package. The “administrator” portion is used for configuration and system set up, and this part of the solution resides on the server machine.

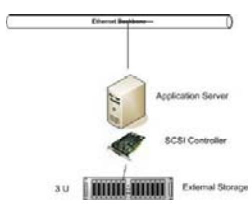
The “operator” module provides for a user-friendly GUI for easy system access by the operator. This “operator” module allows for viewing of live video and recorded video, manual control of PTZ cameras, programming of PTZ tours, bookmarking of events, viewing of alarms and triggers, exporting of recorded video, etc.

Depending on system specifics, a server can handle only a limited number of cameras. Additional cameras can be added using an additional server machine with added computing power. Viewing machines can each typically drive multiple viewing screens (with the ability to display 16 video feeds per screen). Professional DVMS solutions will support multiple viewing machines, either co-located with the server location, or at any remote location (provided a broadband Internet or Intranet connection is available). An “open platform” DVMS solution is recommended, which allows for cameras and encoders from multiple vendors to all be integrated into a single DVMS.

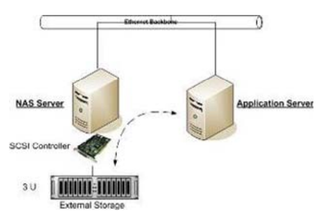
## Server and Storage Design

The storage policy is important to the overall system design and budgeting, and the cost of the storage solution can be significant. For a storage capacity of up about 6 TB, a Direct Attached Storage (DAS) or Network Attached Storage (NAS) architecture would be most cost-effective. However, the fastest and most scalable solution would be a Storage Area Network (SAN) that allows for scaling to 100 TB of storage capacity and beyond. Note that the actual usable storage capacity is always less that the “raw” capacity in the system, due to redundancy in the system, such as RAID and drive sparing.

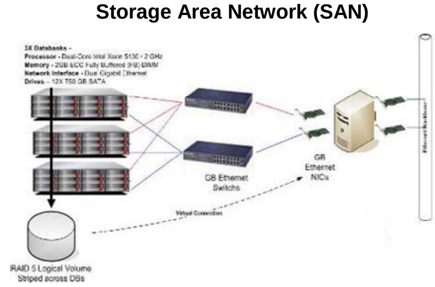
**Direct Attached Storage (DAS)**




**Network Attached Storage (NAS)**




**Storage Area Network (SAN)**




The below table helps in calculating the required storage capacity (based on MPEG-4 encoding). The most common storage policy is to maintain a buffer of stored video for 30 days. Also, it is important to determine the acceptable frame rate and resolution for the stored video streams. Storing all streams at 30 FPS / 4CIF will require significant storage capacity and, thus, will be expensive. As mentioned before, dual stream encoders offer the advantage of making it possible to view streams at a high frame rate while recording the images at a lower frame rate in order to conserve storage space.

*Storage Requirement Per Camera Per Day*

| Storage Requirement per day per camera (GB) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| FPS | 1 | 2 | 4 | 6 | 8 | 10 | 15 | 30 |
| QCIF | 0.06 | 0.12 | 0.24 | 0.36 | 0.49 | 0.61 | 0.91 | 1.82 |
| CIF | 0.24 | 0.49 | 0.97 | 1.46 | 1.95 | 2.43 | 3.65 | 7.30 |
| 2CIF | 0.49 | 0.97 | 1.95 | 2.92 | 3.89 | 4.87 | 7.30 | 14.60 |
| 4CIF | 0.97 | 1.95 | 3.89 | 5.84 | 7.79 | 9.73 | 14.60 | 29.20 |

As an example, the required storage capacity for a system with 10 cameras streaming at 10 FPS / 4CIF with a storage requirement of 30 days is calculated as follows: *10 cameras x 10 FPS / 4CIF x 30 days x 100% duty cycle = 10 x 9.73GB/day x 30 days = ~3TB*

**Monitoring Facility Design**

A monitoring facility can flexibly be designed in accordance with the customer's preferences. Typically, one main monitoring facility will be implemented, with additional remote viewing machines as required. The main monitoring facility generally includes a desk with chairs for the monitoring personnel. At the desk, small viewing screens (17" to 21") are available along with a keyboard, mouse and joystick at each work station for control. In many instances, larger viewing screens are implemented as well, paired with the smaller viewing screens, to allow for larger audiences to view the live and recorded video feeds.

The DVMS "operator" module allows for full customization of which video feeds are displayed at which screen, the size of the video display tiles, locations and grouping of video streams, etc. Most DVMS solutions allow for up to 16 video feeds displayed per screen. Two or even more viewing screens can be connected to each work station, depending on the specific DVMS solution.

**Implementation Strategy**

Once the idea is born to implement a citywide surveillance system, one will encounter many challenges during the journey from concept to operation. This section provides for suggested hands-on steps to help a municipality navigate from the concept stage to the successful deployment and sustained operation of a citywide wireless surveillance system.

- ***Needs Assessment.*** As a first step, it is important to define the goals and expectations in relation to the citywide surveillance system, both initially and in the future. Based on the goals and expectations, it should be possible to derive initial camera locations and basic system specifications that can be used in the feasibility analysis stage. Also, possible overlay applications should be discussed in this initial step. Examples of overlay applications are mobility (enabling broadband access to vehicles) and gunshot location technology.

- ***Feasibility Analysis.*** As a second step, it is recommended to perform a feasibility analysis based on the first step that resulted in initial camera locations and basic system requirements. The feasibility analysis should address both technical and financial feasibility. Public Safety consultants could provide support in this stage at a fee. Alternatively, other cities (that already have deployed a citywide surveillance network themselves) are generally very much willing to share information, and a visit to another city's deployment is a good option as well. Also, you can invite an experienced turn-key system provider to help in the feasibility analysis. For example, Wi4Net will provide tailored design and cost information to cities, based on their individual camera locations and specifications.

- ***Community Discussion.*** It is recommended to discuss the plans for a surveillance system with the council and community early on in the process. This way, it is possible to discuss and agree on objectives for the surveillance system while possible privacy concerns can be addressed appropriately. As mentioned earlier, most systems will offer the ability to block off windows of residential homes in regards to privacy concerns. Part of the discussion may evolve around camera locations and signage / communication.


- ***Funding Strategy.*** The project will only be viable if a strategy can be established to provide for sufficient funding. It is important to consider the complete project cost picture in the funding strategy. The project costs are not limited to the one-time system build-out cost, but also include maintenance charges (most cities review the project cost over a five year period), any service provider monthly access charges and any internal (inter-departmental) charges. Also, monitoring center staffing should be considered. Cities have implemented different policies towards staffing the monitoring center; some cities have implemented staffing on a 24/7 basis, while others only staff the monitoring center during peak activity hours (such as Friday and Saturday nights). Many grant programs are available to help fund citywide surveillance systems (you may refer to the Wi4Net "Securing Grant Funding" white paper for more information). Also, local businesses and construction developers in various cities have shown willingness to help fund surveillance systems in their area. Also in this area, consultation with other cities can be worthwhile.