Urban Network Densification: Solving for Scale

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Executive Summary

Today's knowledge-based economy requires that people have reliable and affordable access to high-speed broadband. In the future, we will see substantial increases in data flows. For example, by 2021, we could see a ninefold increase in video streaming data.[1] The ability for networks to handle these dramatic increases in data flow will be critical.

The shift from building traditional tower networks to small cell wireless mesh networks is dramatic, and the implications for how cities and the industry evolve their business models and processes to accommodate these new networks is essential to effective deployment. This paper was co-developed by Facebook, the City of San Jose and Tech Mahindra to present topics for further study and advance the conversation with lessons learned and challenges on how best to design, deploy and experiment with fixed wireless networks in an urban environment. As these types of innovative business models emerge, it is important not only to adapt to these new technologies, but also to ensure adequate competition and technology neutral access onto city street furniture. This will ensure that small, large and experimental providers can help to advance network deployment to the public's benefit. In particular, the increasing demand for data and the need to serve more people requires a drastic increase in the density of available network capacity, particularly in urban areas.

Cities like San Jose are interested in innovative business models that help to bridge the digital divide, drive competition and provide choice in the broadband market in order to lower costs for their residents. From a public benefit perspective, deployment of networks in an equitable manner is a significant concern for cities and communities around the world.

One possible solution to enable broadband deployment is to use "wireless fiber" technologies that operate in millimeter wave frequencies. These technologies provide multi-gigabit throughput over short and medium distances and potentially can provide mobile backhaul or serve as a "fiber extension" to extend broadband connectivity from existing points of presence ("POPs") to nearby locations. Wireless fiber can deliver last mile access or complement existing wireline services, especially in dense urban environments, resulting in reduced capital expenditures and shorter time-to-market. Currently, these networks are

[1] Cisco, *Cisco Mobile Visual Networking Index (VNI) Forecast Projects 7-Fold Increase in Global Mobile Data Traffic from 2016-2021* (Feb. 7, 2017), *available at* http://www.marketwired.com/press-release/cisco-mobile-visual-networking-index-vni-forecast-projects-7-fold-increase-global-mobile-nasdaq-csco-2193907.htm.

difficult to deploy at scale, and the ecosystem must find ways to deploy more efficiently.

Facebook, the City of San Jose and Tech Mahindra[2] are jointly tackling these densification challenges through a test of Facebook's Terragraph millimeter-wave ("mmWave") technology in downtown San Jose. This public-private sector collaboration is driven by our common interest to explore ways to reduce the digital divide. The City of San Jose specifically has learned ways to build capacity within city departments and make operational improvements to support broadband deployments.

In this paper, we share our learnings in an effort to further drive scale in pre-deployment and deployment processes, with consideration around the initial project management and governance frameworks required to make the implementation successful. We also lay out future areas for process improvements that can further streamline deployment. These topics, and others, will be further explored in future papers. While we have learned a great deal from our collaboration to date, our experience in San Jose suggests some broad areas that the ecosystem will need to consider, including:

1. Establish strategies to efficiently recover field data on the current state of vertical infrastructure assets, devices, structural integrity and power systems efficiently.

2. Make deployment sites as "ready" as possible for equipment installation.

3. Create open and transparent standards and processes that enable and incentivize shared use of infrastructure that can be funded by the private sector and is within a framework that ensures equitable access across the community.

4. Streamline municipal processes. Establish as a goal accelerating permitting and inspections processes that are transparent and predictable for industry and that meet public safety and local design requirements for municipalities.

Ultimately, our objective is to facilitate discussions between ecosystem stakeholders to help accelerate industry momentum around urban network densification that meets the needs of everyone involved.

[2] Tech Mahindra Limited is a multinational provider of information technology and networking technology solutions to the telecommunications industry.

Introduction

The world's population is rapidly urbanizing and increasingly demands data to power online services, such as social media, cloud, video and entertainment. Gartner estimates that more than 20 billion connected devices will be in use by 2020.[3]

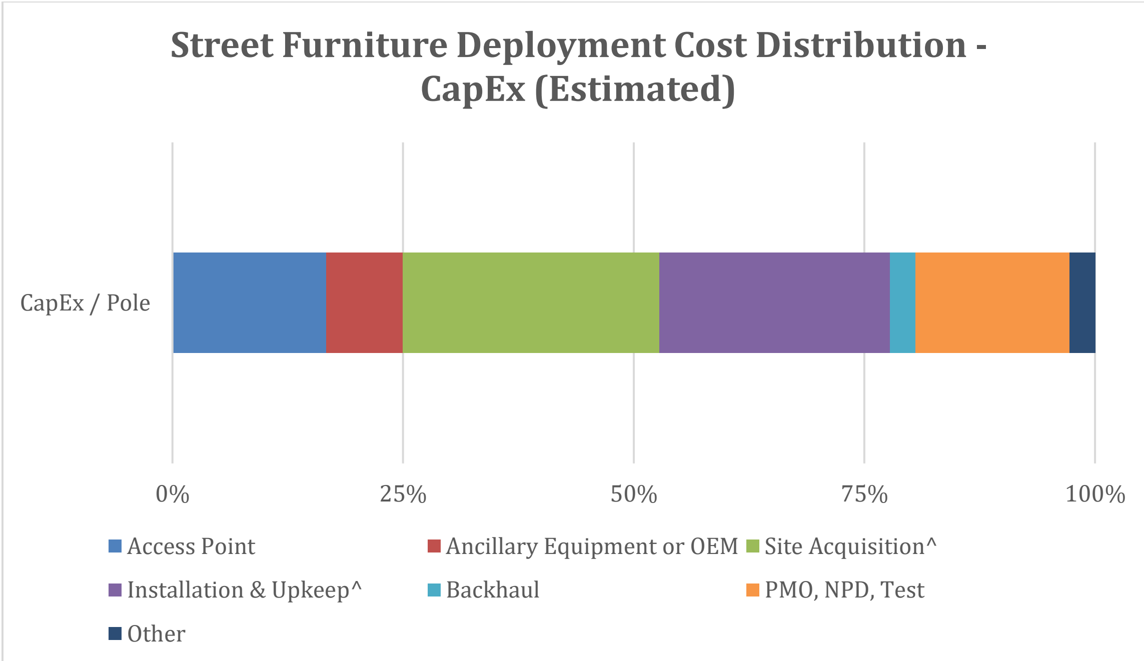
Emerging broadband and Internet of Things ("IoT") capabilities enable many new use cases. These new use cases will strain networks that need to scale to meet the demands for higher throughput, higher number of simultaneous connections and lower latency. Delivering this increased capacity in dense urban networks can be particularly challenging.

Street light poles and traffic signal poles are two important local government-owned assets that can help accelerate broadband deployment. They offer height, city-wide distribution density, and some form of power, which are helpful to the deployment of wireless broadband infrastructure. However, most street lights were not designed to accommodate wireless communications technology. Further, the often heterogeneous nature of this infrastructure significantly increases deployment costs and timelines associated with overlaying wireless communications technologies. Aesthetic and environmental concerns must also be taken into account, as well as governance over this infrastructure, which in some cases is owned by multiple jurisdictions. These challenges present an opportunity for communications services providers ("CSPs"), technology system vendors and urban municipalities to collaborate.

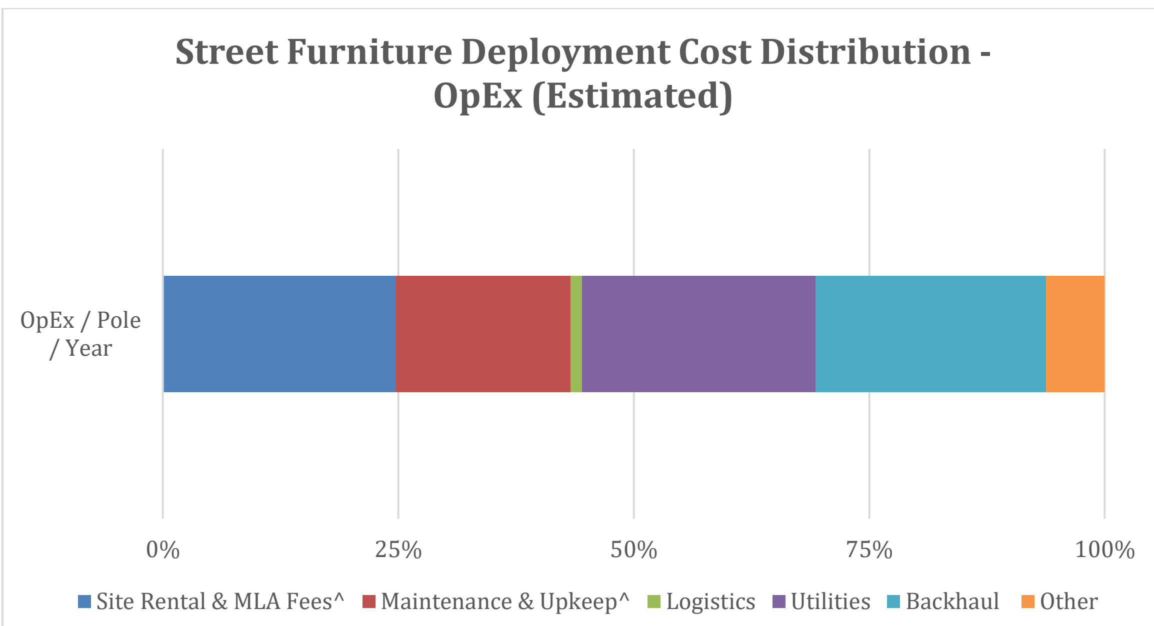
To date, efforts to deploy high-throughput networks at scale have been limited by costs associated with adding a cell site, including site acquisition, civil work, power and backhaul.

For example, below is a chart showing the cost categories and cost distribution to deploy and maintain a small cell site in a typical city in the United States. The cost information shown is based on aggregate data averaged across Tech Mahindra's experience in more than 200 deployments and is not specific to this deployment or deployment in the City of San Jose.

[3] Gartner, *Gartner Says 8.4 Billion Connected "Things" Will Be in Use in 2017, Up 31 Percent From 2016* (Feb. 7, 2017), *available at* https://www.gartner.com/newsroom/id/3598917.



"PMO": Project Management Operations
"NPD": Network Planning and Design



"MLA": Master Lease Agreement

^ Denotes costs that may be reduced through public-private partnerships.

Source: Tech Mahindra (note that the cost information above is derived from and averaged across more than 200 deployments and is not specific to this deployment or deployment in the City of San Jose)

Deployment cost and other limitations can be addressed if cities, CSPs and system integrators ("SIs") partner together. Leveraging street furniture, such as light poles and traffic signals, can make network densification cost effective by reducing expenses related to site acquisition, build out and the provision of power. Cost effective wireless backhaul can significantly accelerate and ease network densification.

mmWave has emerged as a key technology enabler to address the backhaul challenge, given its advantages of small antennas achieving high gain and directivity. Use of unlicensed mmWave spectrum bands, like 60GHz in the U.S., can reduce high spectrum acquisition costs, paving the way for cost effective wireless backhaul. However, use of these higher spectrum bands brings its own set of challenges, including increased propagation loss, required line-of-sight ("LoS") and high susceptibility to blocking. Deploying such wireless backhaul network requires radio sites to be in close proximity of each other and to have LoS access. Poles and other street furniture therefore provide ideal deployment sites for mmWave backhaul networks because of their relative proximity and LoS.

In this paper, Facebook, the City of San Jose and Tech Mahindra share their experiences deploying Terragraph, an outdoor dense urban mmWave backhaul network.[4]

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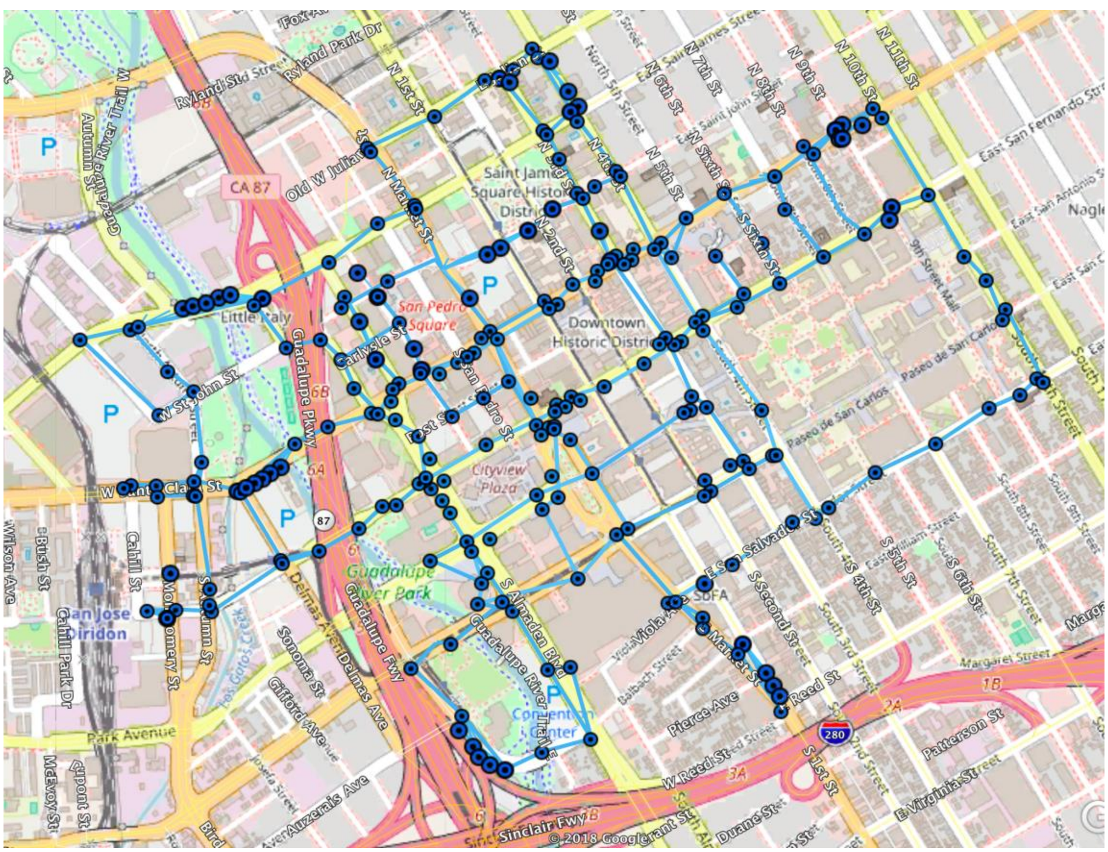
[4] Facebook, *Introducing Facebook's new terrestrial connectivity systems — Terragraph and Project ARIES* (Apr. 13, 2016), *available at* https://code.facebook.com/posts/1072680049445290/introducing-facebook-s-new-terrestrial-connectivity-systems-terragraph-and-project-aries/.

Terragraph San Jose Trial Overview

While an initial testbed network for Terragraph was already in development at Facebook's Menlo Park campus, the Facebook team sought a scaled deployment to support more rigorous engineering testing in a real cityscape. A scaled deployment in a city was also important to provide the team a better understanding of the implementation processes, including planning, design, deployment, operations and maintenance of the network. Under the Smart City Vision and demonstration policies in San Jose, the City aims to become a platform to demonstrate technologies that will benefit their residents.

Over the last year, Facebook, the City of San Jose and Tech Mahindra have collaborated to build out a network across downtown San Jose. This partnership helped meet the goals for the City of San Jose of driving inclusive broadband access. As of late 2017, approximately 250 sites were deployed across 3 square kilometers, offering sufficient scale and complexity to complete engineering tests and validation. Terragraph's implementation in San Jose is among the first scaled 60GHz networks deployed globally, and one of the first to support mesh capability in a real cityscape.

Here is a map of the downtown area of San Jose showing Terragraph node distribution and network links:



For any deployment of mmWave networks in cities, a key criterion for success is a deployment process that is repeatable, within defined cost and deployment timeframes and that can grow predictably as the deployment grows in scale.

In the rest of this paper, we will focus on the team's work with regard to key deployment topics, including site surveys and network planning, making sites ready and streamlining city processes. For each of these areas, we will also detail the challenges we encountered and our recommendations for future deployments.

Site Surveys and Network Planning

What We Did

Surveying and planning was a largely manual process requiring the engineering team to first identify a survey area for the implementation. This was followed by the deployment team performing line of sight, mechanical and electrical surveys. For each area, the deployment team reviewed candidate sites, eliminating targets for several reasons related to LoS issues. In addition to LoS surveys, teams also collected and validated mechanical aspects of the site, including site type, height, thickness and other structures or items on the pole.

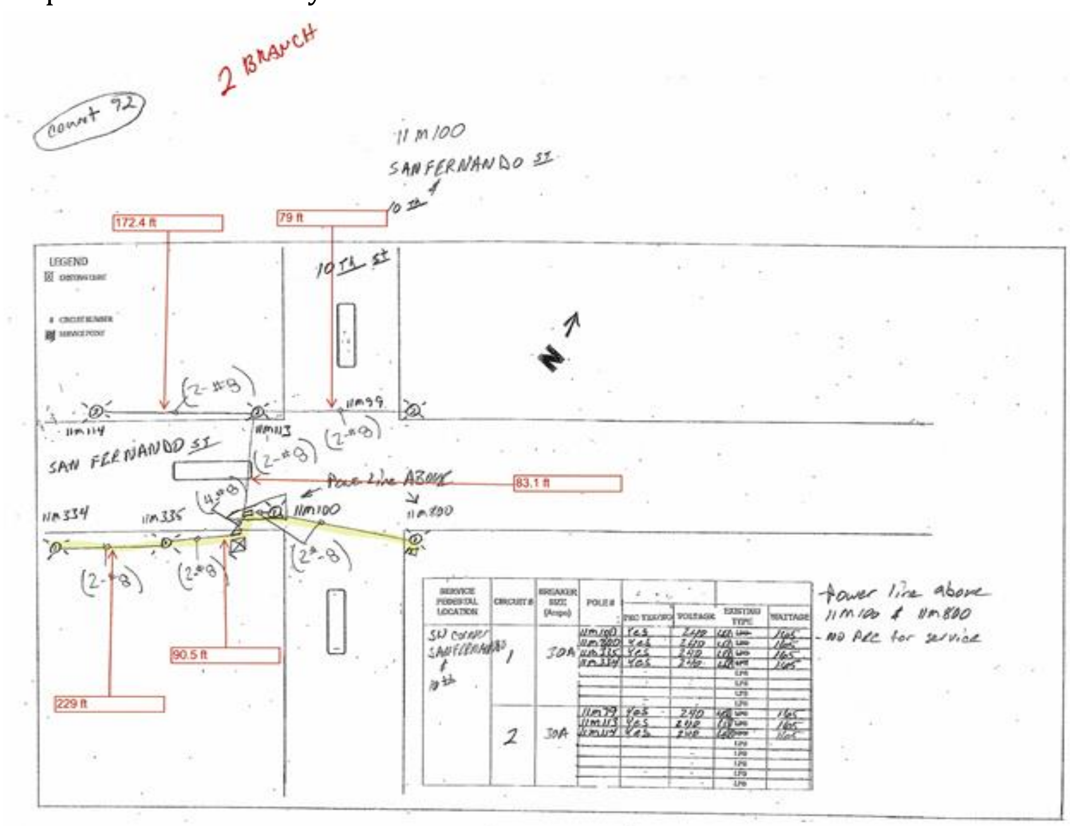
Once a short list of sites was agreed upon by both the City and engineering teams, Tech Mahindra engaged in detailed circuit tracing. After electrical surveys were completed, candidate sites were again comprehensively reviewed by all partners. We then conducted another round of planning, where engineering teams used a set of internal tools to evaluate coverage, redundancy, availability, throughput, capacity and other considerations for those sites relative to test needs.

Example Line Of Sight Survey:

Example Mechanical Survey - Pole Thickness:

Source: Tech Mahindra

Example Electrical Survey:



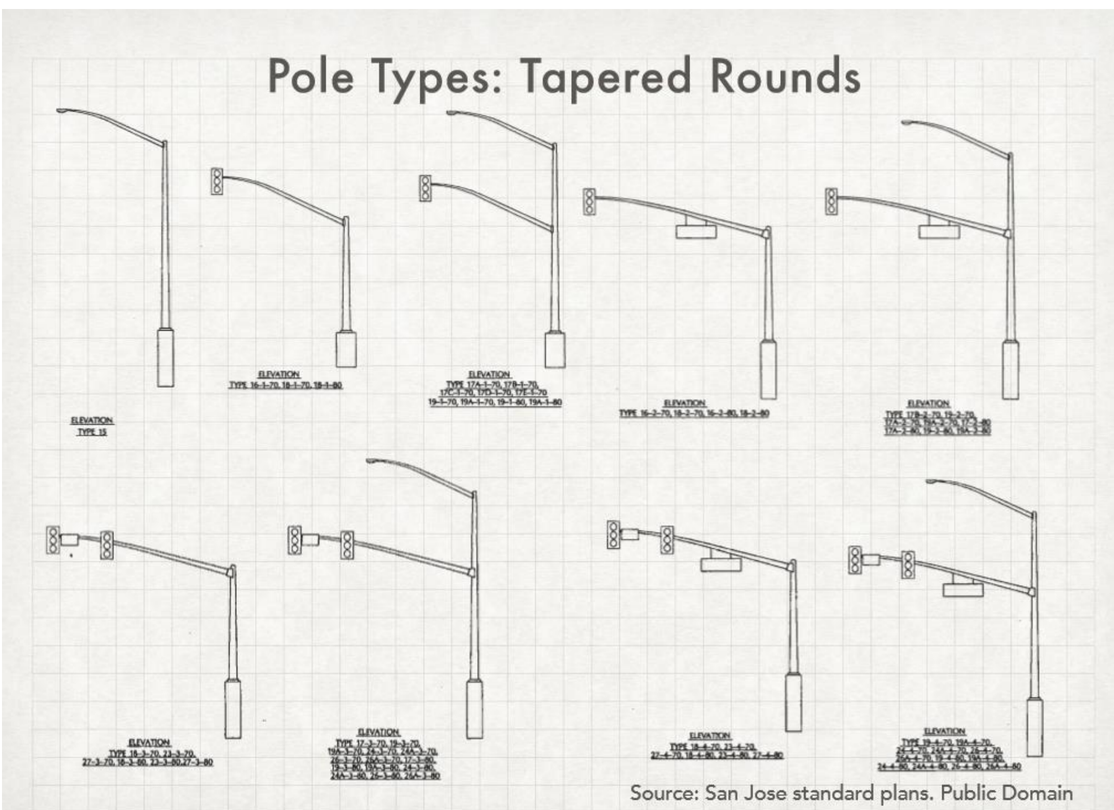
Source: Tech Mahindra

Discussion

Accuracy/Quality of Municipal Records
Geographic Information Systems ("GIS") data provided by the City, such as pole IDs and locations, helped serve as a reference for field survey data. However, the field team estimated that only a small subset of initial site information in city records around power and structure provided up-to-date information. This is understandable given that historically, cities have only required the data necessary to maintain a pole for lighting purposes, which is a very small subset of the data necessary to attach multiple wireless devices. Furthermore, many poles in San Jose were inherited through land acquisition, resulting in a very heterogeneous collection of assets with limited and mostly analog forms of documentation.

Site Diversity
To achieve the necessary density and coverage, the deployment used more than light poles and traffic signals. It also used ornamental, utility and transit authority poles that are managed by different local authorities, which created additional complexity.

Example Pole Types:



Source: San Jose standard plans (Public Domain)

Rigid Engineering Considerations
Ultimate site selection involved consideration of a number of factors, including target network performance, cost, ease of implementation and others. Practical considerations including power availability and asset ownership limited the pool of available sites and often ultimately took precedence over purely engineering parameters like LoS and network performance. In some cities, the potential requirement for and availability of metering could also be a consideration.

Asset Tracking
Existing systems for gathering and tracking asset attributes (sites, circuits) were inadequate and involved manual processes, leaving some records quickly outdated. Supporting systems and municipal initiatives around digitization and real-time asset tracking could greatly streamline the survey process.

Better asset management would have reduced contractor costs and time to look at city assets and reduced the impact of errors and teams incorrectly tracking data. This would have allowed the City to spend less time reviewing permitting and design submissions, ensuring that municipal assets are properly and efficiently utilized. The City is reviewing these lessons learned and exploring how to improve records moving forward.

Data Gathering & Network Planning Tools
In San Jose, site survey involved a substantial amount of manual processes, which were often time consuming, expensive and error prone. As discussed above, this process required multiple site visits by various crews, including teams to assess LoS, electrical contractors to assess sufficiency of electrical supply, as well as structural engineers to evaluate pole integrity and determine the need for any structural remediation.

These issues are characteristic of overlaying a modern communications network on urban infrastructure that was not designed, engineered or maintained to support that network. We hope to establish strategies to cost effectively recover field data on the current state of vertical infrastructure assets, devices, structural integrity and power systems and enable municipalities and other stakeholders to maintain this data going forward.

Some possible strategies include:

1. Development and use of network planning tools to help automate site survey processes such as candidate pole selection, capacity planning and site count rationalization. For example, the use of Artificial Intelligence (AI), Light Detection and Ranging (LIDAR) and Computer Vision might help cut down the cost and time associated with site surveys and network planning. Using such tools in this deployment would have reduced the manual effort related to sending people out to look at sites, as we we often had to send out crews multiple times to evaluate LoS. It would also have accelerated network planning

efforts, with fewer errors than manual site selection, and resulted in an optimized design. The City of San Jose plans to explore options for this kind of mapping project through future demonstration projects. However, it should be noted that consortiums or industry associations of broadband providers may benefit from co-investing or offering grants to cities for infrastructure mapping to reduce costs of deployment for all providers.

2. Adopting city and industry standard tools to store and maintain infrastructure data. Given the importance of reliable infrastructure data for deployment of these networks, it is essential to invest in standardizing the data and information needed for accurate deployment, as well as re-training workers to follow these procedures. Developing these standards and retraining the workforce takes a modest investment, but can have long lasting benefits.

3. Requiring that data be contributed to a centralized repository as part of any upgrade to urban infrastructure, especially if it is funded through any consortiums or grants to help upgrade the infrastructure. However, adequate security protocols should be developed to protect this critical information from bad actors.

Informing 5G Technology Deployments

The lessons learned and our experience in San Jose should help to inform deployment best practices for other technologies using mmWave spectrum, including 5G. 5G technologies that operate in the microwave band will face similar deployment challenges to what we faced in San Jose, such as limited range in the mmWave bands.

Making Sites Ready for Equipment Deployment

What We Did

We made a substantial effort to understand the state of current city assets, especially around mechanical and electrical systems. Once we gathered data on these aspects, the team engaged in post-processing to determine the work required to make sites ready for network deployment. Proposals for site remediation were delivered to the City for comments and approval, which the City addressed on a case-by-case basis. Once approved by the City as part of the permitting process, city certified civil and electrical crews executed on the remediation. Electrical remediation often involved multiple elements on the circuit and not just on the pole where the equipment was installed.

More detail on the mechanical and electrical remediation that sites required before deployment is provided below.

Mechanical Remediation
The mechanical and structural data gathered in the visual site survey process was supplemented with the additional mechanical data of the radio equipment installed on the sites. We conducted a structural analysis using this combined data. This analysis determined the need for, and the extent of, any mechanical remediation for each site.

Typical areas of remediation we encountered include damaged poles or pole foundations, poles overloaded with equipment and instances where the pole in question did not exist. Possible remediation included altering the position of equipment on pole sites, removing existing pole loads and replacing elements of the pole or pole foundation.

Electrical Remediation
The circuit tracing data gathered in the electrical survey process was supplemented with the additional load from the radio equipment that will be installed on the sites. To eliminate errors and to automate electrical analysis a 'Voltage Drop Measurement Calculator' was developed. This stage also involved digitizing the hand drawn circuit designs.

The elements for electrical remediation include:

- Need for continuous power (for example, centralized timers on serial circuits)
- High-voltage drop
- Current exceeding breaker limits

- Deprecated or unsafe electricals

Suggested remediation included:

- Replacing lamp heads with LED
- Larger capacity breaker
- Newer wires
- Split circuits
- Pole replacement

Example: Voltage Drop Measurement Calculator

Service Pedestal Location	Circuit #	Circuit Voltage	Circuit Breaker Amperage	Pole ID	Type of Load	Existing Wattage	Proposed New Wattage	UNLL	Existing Current (Amps)	Proposed Current (Amps)	Existing Voltage Drop (max %)	Proposed Voltage Drop (max %)
N Fourth St and E Santa Clara St NWC	2	240 Volts	30 Amps	11M985	LED Lamp	130	-	no	4.08	6.08 (max possible draw)	0.45%	0.62%
				11M403	LED Lamp	130	-	no				
				11L21	LED Lamp	180	-	no				
				11L9	LED Lamp	180	-	no				
				11L22	LED Lamp	180	-	no				
					Wifi AP	-	-	no				
					Network Switch	-	14	yes				
					TG2	-	44	yes				
					Max power supply draw: 240 watts/1.0 A							
				11L120	LED Lamp	180	-	no				
					Wifi AP	-	15	yes				
					Network Switch	-	14	yes				
					TG3	-	63	yes				
					Max power supply draw: 240 watts/1.0 A							
UNLL = Unmetered Non-Lighting Load				Total Unmetered Non-Lighting Loads			150 watts					

Source: Tech Mahindra

We recommend that similar deployments use this 'Voltage Drop Measurement Calculator' as a standard procedure to streamline the process for electrical remediation.

Discussion

The entire process of making sites ready for implementation was both time consuming and costly. It required the following:

1. **Remediation Planning** – The process of learning attributes of city street furniture was complex, requiring multiple site visits to assess mechanical and electrical readiness. The necessary remediations often varied by site, requiring City resources to review and approve each on a case-by-case basis.

2. **Remediation Execution** – Execution of the remediation was also complex. Material required to successfully deliver on required remediations had significant lead-times. Appropriate city-certified contractors to execute on the required remediations were also in short supply, as they were often stretched across multiple initiatives. Coordination of materials and contractors during

appropriate installation windows was often a challenge. A large portion of the network planning process was a result of sites not having electrical or structural attributes suitable for implementation. Site preparation was a major cost element.

3. **Numerous Site Visits** – The planning remediation and installation process warranted at least six site visits: initial survey, circuit tracing, remediation, installation, inspection and meter installation. The ecosystem should consider means of rationalizing processes to reduce cost and decrease buffer times between visits.

Support Make Ready Initiatives
This model of network deployment requires using existing street furniture that was not purpose built to support network equipment. The term 'make ready' is often used to characterize a range of efforts, including relocating cable to allow new or additional attachments on street furniture, to electrical and structural engineering and construction work necessary to make the street furniture safe for an attachment.

In San Jose, some of the poles were damaged and unable to support the weight and wind shear of a vertical attachment without replacing the base, the pole or both. Even more challenging, many street light power systems – including in San Jose – are controlled by the adjacent traffic light control system. The traffic light control system that powers the street lights is based on a timer, and the poles did not receive power around the clock. In these situations, extensive electrical engineering design and construction is necessary to safely power the attachments to the pole around the clock. Additional electrical metering requirements also make this remediation even more challenging.

These are just a few of the real-world make ready challenges facing local authorities and infrastructure providers. Initiatives to help make sites proactively ready for network implementations would significantly lower the cost of deployment and reduce the time needed to deploy similar networks. However, neither the public nor private sectors have yet found a business case to justify proactive remediation. The private sector typically supports remediation and make ready work for the immediate task at hand. As multiple attachments are added, additional remediation and make ready work may be necessary.

It is important to recognize that electrical and structural remediation is often more complex than anticipated on street furniture, especially on light poles. Ensuring high-quality work that is safe and respects the equipment of other providers on the pole is important as we think about how to deploy networks.

Support Equitable Sharing of Infrastructure & Costs
Appropriate mechanisms for burden sharing among ecosystem participants can also accelerate deployments, reducing the disadvantages of large initial capital outlays

and also preventing players from being "locked out" as a result of overuse by existing infrastructure users (e.g., being squeezed out of conduit, pole real estate, circuit capacity).

Make ready initiatives and frameworks for sharing infrastructure can be powerful in reducing cost, time and complexity of deployments for service providers and municipal staff, while also accelerating access to broadband services to members of the community.

Burden sharing might take the form of a joint provider agreement ("JPA") across local authorities and infrastructure providers so that poles become "future proofed" by the first infrastructure user. That first infrastructure user would then be reimbursed fairly by the JPA via a private sector contribution for the remediation and make ready work done, which can be shared by future users.

Here are some suggestions for further exploration:

1. Establish design standards for power and structural integrity that ensure sufficient and continuous power availability and access to enable shared use of poles (and other shared infrastructure) that meet the business needs for providers as well as public safety, aesthetic and community needs for a city.

2. Implement joint powers authority for poles and other shared infrastructure with approved third parties to perform work. Though, in some jurisdictions, existing contracts may exist that may take priority over new agreements.

3. Enable cost recovery; in particular, fair and equitable contribution mechanisms that allow recovery of investment costs by the first mover.

Streamlining City Processes

What We Did

The City of San Jose sought to streamline the municipal processes for permitting to deploy this new technology, agreeing to expedite permitting decisions to deploy a reasonably scaled network in a short period of time. With that said, current processes involve many city departments. As interest in network densification grows, it is unclear whether other municipalities are sufficiently scaled to focus on and resolve inbound requests from a variety of players. In the future, San Jose plans to continue to streamline permitting processes to make it easier to deploy and increase transparency for all providers.

Alignment on Goals & Priorities
City officials sought to align the goals and priorities among all of the stakeholders. The keys to successful alignment were: (1) executive sponsorship; and (2) a single designated point of contact for all stakeholders to facilitate communications. First, City officials including the Mayor and the Mayor's office, the City Manager's office and the Department of Public Works supported the project and its stated goals. This allowed the City to designate a Primary City Stakeholder. Second, the Primary City Stakeholder served as the single point of contact for participants in the project. This essential role helped navigate across multiple municipal organizations, as well as guide discussions with other agencies, such as utilities, that have a stake in the City.

By facilitating communications among and input from all the project participants, the City was able to establish a mutually agreeable governance model and cadence, ensuring alignment on deployment schedules and a clear understanding of the processes and the status of the deployment across all stakeholders. This also ensured that any challenges or issues were raised as early as possible to relevant teams and stakeholders.

Permitting Processes
Early in the process, the City incorporated input from all partners in the project to establish templates and means of performing key calculations, and set the cadence for permit submittals and approvals. One of the changes that all parties found beneficial was to implement batch processing of permit requests. In addition to saving time, insight into a broader view of the project allowed for better and more consistent decisions.

Installation & Inspections
Once permits were approved, deployment teams coordinated with the City to identify installation windows. Like any deployment on city streets, these installation windows were scheduled so as not to interfere with city activities, such as construction, maintenance, peak traffic or special events. Once the installation was completed, the City needed to inspect the sites. This stage was well planned,

and deployment teams provided site permits to inspectors for review beforehand. Giving the structural and electrical inspectors time to review the site permits prior to the actual inspection facilitated approvals and avoided duplicating work. A sample inspection record is shared in the Exhibits to this document.

Discussion

The City of San Jose provided strong leadership and stewardship throughout the deployment. But this may not always be the case for other deployments. Some areas that the ecosystem should continue to consider:

Transparency & Streamlining around City Processes
Cities should discuss ways of ensuring clarity and streamlining processes to reduce complexities in the permit and inspection processes across various departments. Additional municipal staffing in these areas could also help expedite deployments.

Skill Development
Current deployment requires crews with different skills and certifications for mechanical and electrical installation and remediation. There is an opportunity to create new education and certification programs that can eliminate bottlenecks related to resource availability and accelerate the process in general.

Strong Stakeholder Buy-In
A well-positioned, empowered city champion for the program was critical in helping navigate through various city and civic organizations. During the duration of this project, the team's main point of contact was extremely successful in rallying the right city teams to review permits, to execute on inspections and also to work with members of the community interested in learning more about the project. Without the appropriate champions, the project would have much more challenging to execute. In fact, the San Jose City Council recently approved a Digital Inclusion and Broadband Strategy that directs the consolidation of broadband governance into a single team and directs the creation of an integrated Vertical Attachment Team across several departments.

Start Small, Scale Fast
By running a few, select sites that represent the majority of variance to be encountered through the site selection process alongside the city and vendors, we were able to quickly establish norms and ways of working, and identify engineering and technical hurdles. Mock poles were staged first at Facebook's Menlo Park campus, and then in the City. Templates and tooling for permitting and other processes were also built to support larger scaling. Spending more time on quality from the start reduced the number of review cycles and buffer times.

Quality Control & Error Logs
Prior to submission of each batch of permits, the Facebook and Tech Mahindra teams introduced additional reviews to ensure quality control. This was important in saving city resources and time, and in ensuring continued trust in data between teams. A common error log after each review by the City was introduced and shared across the team, so that all parties were aware of the errors, and the learnings were fed back so as to improve ongoing submissions.

Utility Company Engagement
Utilities, CSPs and SIs should consider streamlining processes for improving smart meter procurement, tariff collection and power turn-up. Each of these can cause potential delays in network rollout. For example, the City's tariff agreement structure would need to be updated to in order to deploy at scale. The new structure would ideally better align the incentives of cities, service providers and the utilities to enable efficient deployments.

Mock Pole in Menlo Park:

Source: Tech Mahindra

Stakeholder Alignment
As mentioned above, our project benefitted from strong alignment among the stakeholders within the City of San Jose, and from an engaged executive sponsor. This in turn contributed to strong alignment between Facebook, the City of San Jose and Tech Mahindra teams as the project progressed. Processes were extremely transparent. While implementation was certainly not flawless, teams always felt informed about the necessary steps.

We know that such alignment may not always be the case in every deployment. However, lack of alignment and transparency can have costly negative consequences ranging from schedule delays to expensive rework if decisions have to be revisited. As market players plan on more substantial implementations in San Jose in the future, we know that existing resources will be challenged in scaling to the anticipated demand, unless processes are effectively streamlined and existing resources augmented.

Conclusion

Demand for online data continues to grow as urban populations become more connected. Smart City technologies and services, connected devices and other new applications will continue placing even greater demands on the network. This represents a significant opportunity for the ecosystem as a whole. To meet the growing demand for bandwidth, ecosystem partners need to come together and propel urban network densification into the mainstream and solve for scale deployment.

With the emergence of mmWave as a key technology enabler for wireless backhaul, coupled with the collaboration of the ecosystem to knock down costs and utilize street furniture, the potential of urban network densification is now within reach. This will require strategic collaboration between cities, CSPs, vendors and SIs. Lessons learned from our experience in San Jose are especially important as we think about deployment of other technologies that employ mmWave spectrum, including 5G.

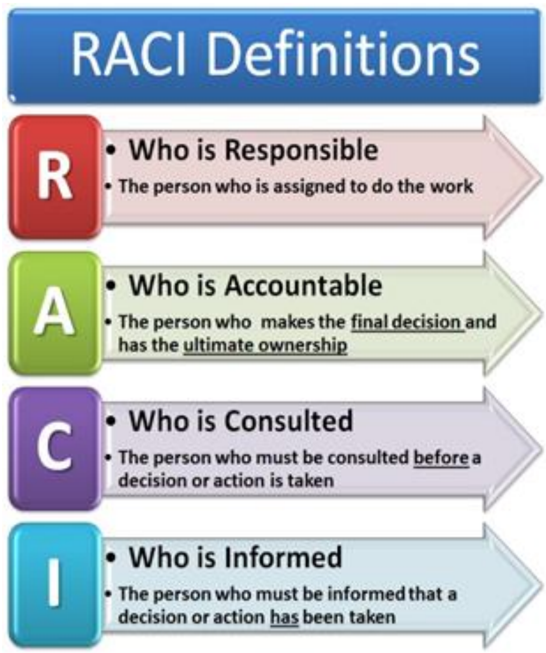
To make urban network densification with mmWave a feasible and repeatable process across varied geographies, the ecosystem must address a number of factors through collaboration between companies and municipal partners.

This white paper shares our experiences, learnings and observations from the San Jose mmWave network test deployment. We have described key opportunities for cities, CSPs, vendors and SIs to work together to accelerate connectivity to communities, while substantially reducing burdens for providers and municipal resources.

This is just the start. We hope this paper will help foster strategic dialogue and collaboration with ecosystem players to explore opportunities that further advance urban network densification and solve for scale.

Exhibits

Responsible, Accountable, Consulted, Informed (RACI) Matrix



Task Name	Stakeholder		
	FB	TechM	SJC
A. LoS Survey			
Create List of Sites	C	R,A	I
Obtain Site Details from Owner / Stakeholder	I	R,A	
Undertake LoS Survey	I	R,A	
Assess LoS Information	I	R,A	
Propose Remediation Strategy to SJC / Stakeholder (if required)	C	R,A	I
Obtain Consent to Remediation Strategy (if Required)	I	A	R
Advise Design Team and prepare alternative candidate for failed Ground LoS	I	R,A	
B. Mechanical Survey			
Prepare Mechanical Survey Worksheet for site	I	R,A	
Obtain consent to site (if required)		R,A	
Undertake Mechanical Survey of Site (capture relevant data of site)	I	R,A	
Assess Mechanical Remediation requirement	I	R,A	
Prepare Mechanical Survey Report for commercial review	C	R,A	
Propose Mechanical Remediation Strategy to SJC / Stakeholder (if required)	C	R,A	I
Obtain Consent to Remediation Strategy (if Required)	I	A	R
Report of SJC / Stakeholder's Consent to remediation works	I	R,A	
C. Structural Analysis			
Prepare Structural Analysis Worksheet for site	I	R,A	
Obtain consent to site (if required)		R,A	
Undertake Structural Analysis data collection of Site (capture relevant data of site)	I	R,A	
Prepare Structural Analysis Report for engineering review	C	R,A	
Advise Project Team of Successful Sturctural Analysis	I	R,A	
Advise Design Team and prepare alternative candidate for failed Structural Analysis	I	R,A	
D. Mechanical Remediation Permit Application			
Compile relevant templates with reports and consents for submission	I	R,A	
Review / Submit Application	I	R,A	
Approve Application	I	A	R
Advise Project Team of Successful remediation permit	I	R,A	
if required, prepare alternative strategy for rejected permit application	I	R,A	
Advise Project Team and all relevant Stakeholders to prepare alternative candidate for rejected remediation permit	I	R,A	

E. Electrical Survey			
Conduct circuit tracing of the site	I	R,A	
Record circuit load	I	R,A	
Create TG Equipment Electrical Block Diagrams	I	R,A	
Prepare Local Utility/Owner Review Documents	I	R,A	
Submit documentation for Local Utility Review	I	A	R
Formalise circuit diagrams for inclusion on CD set	I	R,A	
Prepare Permit Table of Remediations	I	R,A	
F. Electrical Remediation Permit Application			
Compile relevant templates with reports and consents for submission	I	R,A	
Prepare Traffic Control Plan Permit	I	R,A	
Prepare Construction Drawings	I	R,A	
Review / Submit Application	I	R,A	
Approve Application	I	A	R
Advise Project Team of Successful remediation permit	I	R,A	
Advise Project Team and all relevant Stakeholders of requirement to prepare alternative strategy for rejected permit application	I	R,A	
Advise Project Team and all relevant Stakeholders to prepare alternative candidate for rejected remediation permit	I	R,A	
G. Electrical Remediation Works Preparation / Staging			
Procure electrical remediation equipment / materials	I	R,A	
Schedule Electrical remediation works	I	R,A	
Obtain consent to site (if required)	I	R,A	
Undertake Electrical remediation works	I	R,A	
Inspection of Electrical remediation works	I	A,C	R
Re-work of Electrical remediation works (if necessary)	I	R,A	
H. PoP Survey			
Review Site as a POP	I	R,A	C
Obtain consent to site (if required)	I	A	R
Undertake site walk to determine conduit and cabling requirements	I	R,A	C
Undertake POP Site Survey	I	R,A	C
Assess site Information	I	R,A	I
Propose Remediation Strategy to SJC / Stakeholder (if required)	I	R,A	C
Obtain Consent to Remediation Strategy (if Required)	I	A	R
Prepare remediation Report for approval	I	R,A	I
Advise Project Team of Successful POP site permission	I	R,A	
Advise Design Team and prepare alternative candidate for rejected POP site approval	I	R,A	

I. POP Site Remediation Works Preparation / Staging			
Procure Network Remediation Equipment	I	R,A	
Stage Electrical Remediation Equipment	I	R,A	
Schedule POP site remediation works	I	R,A	
Obtain consent to POP site (if required)	I	R,A	C
Undertake Remediation works for POP site	I	R,A	C
Inspection of POP site remediation works	I	A,C	R
Re-work of POP site remediation works (if necessary)	I	R,A	I
J. Installation Permit Application (Cx NTP)			
Compile relevant templates with reports and consents for submission	I	R,A	
Prepare Traffic Control Plan Permit	I	R,A	
Prepare CD & Insurance Application	I	R,A	
Attach Government Standards, Photos, Drawings, Area Map, Permit Templates	I	R,A	
Review / Submit Application	I	R,A	
Approve Final Application	I	A	R
Advise Project Team of Successful remediation permit	I	R,A	
Advise Project Team and all relevant Stakeholders of requirement to prepare alternative strategy for rejected permit application	I	R,A	
Advise Project Team and all relevant Stakeholders to prepare alternative candidate for rejected remediation permit	I	R,A	
K. Cx Build & Installation Tasks			
Procure TG Installation Equipment	I	R,A	
Procure Non-TG Installation Equipment	I	R,A	
Stage TG Equipment	I	R,A	
Stage Non-TG Equipment	I	R,A	
Create Installation Checklist for site	I	R,A	
Configure POP	R	A	
Configure E2E Controller	R	A	
Install TG / non-TG equipment on site	I	R,A	
Install Electrical Metering equipment		R,A	C
Inspect TG Installation	I	A,C	R
Activate TG Radios	C	R,A	
Rework TG Installation (if necessary)	I	R,A	
Test TG Installation	R	A	

Sample Permit Application

CITY OF SAN JOSE
CAPITAL OF SILICON VALLEY

Department of Public Works

Permit Application

Engineering Services Division
Structural Engineering and Code Inspections

Staff will assign **PERMIT NO.**

FOR ALL TYPES OF BUILDING PERMITS
Use this form to apply for a building, electrical, mechanical, or plumbing permit. Check all that apply.

THE APPLICANT MAY BE:
- A Licensed Contractor
- An Owner-Builder (all property owners who apply are "Owner-Builders")
- An Agent acting for the Contractor or Owner-Builder. See page 2 of this form to authorize an agent.

NOTE TO OWNER-BUILDERS
In compliance with state law, the City will provide you with a notice and the Owner's Acknowledgment and Verification of Information Form that explain the legal implications of construction on your property. You will need to sign and submit this acknowledgement prior to permit issuance.

NOTE TO CONTRACTORS
Complete this permit applicaton before getting counter service. To verify license information, visit:
- Contractors State License Board website: www2.cslb.ca.gov/onlineservices/CheckLicenseII
- City of San José Business Tax: http://www3.csjfinance.org/bizlic/bizlicForm.asp

Central Service Yard
Engineering Services
Structural Engineering and Code Inspections

PROJECT IDENTIFICATION All applicants must fill out this section

PROJECT ADDRESS:	
APPLICANT Name:	
Address No.-Street:	City-State-Zip:
Email:	Phone:
***LEGAL OWNER** (if different from Applicant) **Name:**	
Email:	Phone:
DESIGN PROFESSIONAL IN CHARGE if any Firm Name:	State License #:
Address No.-Street:	City-State-Zip:
Email:	Phone:
PERMIT TYPE Check all that apply to the project: ■Building ■Electrical ☐Mechanical ☐Plumbing	
BRIEFLY DESCRIBE SCOPE OF WORK: Installing Terragraph Radio Equipment on various streetlights and signal poles	

DECLARATIONS All applicants must fill out this section. Signature applies to both declarations.

A. WORKERS' COMPENSATION DECLARATION. WARNING: Failure to secure workers' compensation coverage is unlawful and shall subject an employer to criminal penalties and civil fines up to $100,000, in addition to the cost of compensation, damages as provided for in Labor Code Section 3706, interest, and attorney's fees. I hereby affirm under penalty of perjury one of the following declarations:

Check only one box:

a) I have and will maintain a certificate of consent to self-insure for workers' compensation, issued by the Director of Industrial Relations as provided for by Labor Code Section 3700, for the performance of the work for which this permit is issued. My policy number is:

b) I have and will maintain workers' compensation insurance, as required by Labor Code Section 3700, for the performance of the work for which this permit is issued. My workers' compensation insurance carrier and policy are:

CARRIER:	PHONE:
POLICY #:	EXPIRES:

c) I certify that, in the performance of the work for which this permit is issued, I shall not employ any person in any manner so as to become subject to the workers' compensation laws of California, and agree that, if I should become subject to the workers' compensation provisions of Labor Code Section 3700, I shall comply with those provisions.

B. DECLARATION REGARDING CONSTRUCTION LENDING AGENCY. I hereby affirm under penalty of perjury that there is a construction lending agency for the performance of the work for which this permit is issued (Civil Code Section 3097). If not using a construction lending agency, write N/A.

LENDER'S NAME:
LENDER'S ADDRESS:

● SIGNATURE Licensed Contractor, Property Owner OR Authorized Agent PRINT NAME DATE

continued>

*The Applicant and Legal Owner, if different, are beholden to have a contract authorizing improvements to a property.

Sample Inspection Record

CITY OF SAN JOSE
CAPITAL OF SILICON VALLEY

Permit Record

PUBLIC WORKS PERMIT INSPECTION RECORD

Permit #:

Project Location:

Permit Date:	TERRAGRAPH WIRELESS PROJECT

Permit Approvals Granted: Building and Electrical

APPLICANT:
CONTRACTOR:
Permit Tech:

SCOPE OF WORK:

A. INSTALL AC TO DC POWER SUPPLY AND ENCLOSURE ON 18 POLES
B. CONVERT LIGHTING CIRCUITS TO CONTINUOUS POWER AS REQUIRED
C. REPLACE EXISTING LAMP HEADS WITH LED LAMP AS REQUIRED

THIS PERMIT MUST BE POSTED ON DAY OF INSPECTIONS

Conditions:
SECI SUPERVISING INSPECTOR:
SECI BUILDING INSPECTOR:
SECI ELECTRICAL INSPECTOR:

Final Inspection Record

See other side for interim inspection record

Trade	Inspection	Date	Approved By
BUILDING			
ELECTRICAL			

FIRE INSPECTIONS (408) 535-3555		
Life Safety Systems Cont'd	Date	Inspector
Emergency Lighting		
Fire Rated Construction		
Fire Extinguisher/ Street Address		
P.S. Radio Coverage		
Access/ Hydrants		
Alternate Materials		

Coding: PA = Partial Approval CN = Corrections Notice NR = Not Ready CO = Consultation Only

Inspection Item	Date	Coding	Inspectors Name	Corrections Verified Date Initials

Source: Tech Mahindra