Chapter 5

Smart Community Wireless Platforms: Costs, Benefits, Drawbacks, Risks

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Additional information is available at the end of the chapter

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Abstract

A wireless network covering most of the city is a key component of a smart city. Although the wireless network offers many benefits, a key issue is the costs associated with laying out the infrastructure and services, making the bandwidth available and maintaining the services. We believe community involvement is important in building city-wide wireless networks. Indeed, many community wireless networks have been successful. Could the city inspire and assist the communities with building their wireless networks, and then unite them for a city-wide wireless network? We address the first question by presenting a model where municipality, communities and smart utility providers work together to create a platform, smart community wireless platform, for a community where platform sides work together toward achieving smart community objectives. One challenge is to estimate the total cost, benefits and drawbacks of such platforms. Another challenge is to model risks and mitigation plans for their success. We examine relevant dynamics in measuring the total cost, benefits, drawbacks and risks of smart community wireless platforms and develop models for estimating their success under various scenarios. To develop models, we use an intelligence framework that incorporates systems dynamics modelling with statistical, economical and machine learning methods.

Keywords: smart community wireless platform, cost of community wireless networks, benefits of community wireless networks, smart community, system dynamics modeling

1. Introduction

A smart city aims to embed digital technology across city functions including its economy, mobility, environment, people, living and, governance. Many cities have taken initiatives toward becoming a smart city to foster commercial and cultural development. A wireless network (e.g. Wi-Fi network) covering most of the city is a significant contributor and a major step toward becoming a smart city. Such a network offers many benefits in tackling challenges such as reducing traffic congestion, reducing crime, fostering regional economic growth, managing the effects of climate, and improving delivery of city services [1].

City-wide wireless networks are still desired even with the availability of cellular networks, mainly due to their low cost and higher bandwidth compared to cellular networks. Plus, people are more inclined to use the wireless networks where available as opposed to using their limited data plans. In addition to citizens, many smart IoT devices will require bandwidth and many of them will use protocols which are best supported by a city-wide wireless network.

One major issue with city-wide wireless network is the high cost of laying out the infrastructure, rolling out the services, allocating adequate bandwidth, maintaining the services. One question is who will setup the network and who will pay for it. A second question is who will supply the bandwidth while broadband bandwidth is still in shortage in most cities. Another question is who will pay for the supplied bandwidth.

What should the cities do? Should they rely solely on the wireless operators to build a wireless network across the city? In general, it is unreasonable to expect the private sector to setup a wireless network for smart city objectives. If not private sector alone, then how about some private-public partnerships? Despite numerous attempts in prior years, private-public partnerships and joint ventures between municipalities and private companies have failed to take hold. Furthermore, several states have enacted legislation to prevent municipalities from offering wireless services in many forms in the city for variety of reasons [2]. While there are so many failures in the past and there is political controversy, why should they still pursue a city-wide wireless network? Should they simply give up on their goals of being a smart city? How could they maintain their competitiveness without a wireless network in the digital age?

We think that cities could look for new approaches in realizing city-wide wireless network. One approach is to analyze the success of community wireless networks and try to find ways to leverage their success for building a city-wide wireless network. Indeed, there are many examples of successful community wireless network implementations [3, 4]. In this paper, we will bring attention to successes of community wireless networks and develop a model where municipality, communities and smart utility providers work together to create a platform, which we call smart community wireless platform, where different platform sides work together toward achieving smart community objectives. The purpose for this investigation is to take a new look at building a city-wide wireless network through a new model based on integrating smart community wireless networks over the span of the city. The objective of this paper is to present this platform and its various dynamics. Accordingly, the paper takes more of a conceptual approach rather than a technical one. The purpose is to introduce the smart community wireless platform. How such platforms could join to form a larger city-wide wireless network is a separate discussion we address in [5].

2. Smart community wireless platform

Earlier approaches involving municipality partnering with private commercial providers failed for variety of reasons [2, 6, 7]. We believe smart city starts with smart communities and hence the community involvement is significant in building a city-wide wireless network. We use the term smart to indicate the human factor in building and using the wireless network. Indeed, many community and neighborhood wireless models have been successful. The proposal is take it further through collaborations of communities, municipalities and other partners to realize a city-wide wireless network. In our approach, we will include the smart utility providers as a player in the platform. The question becomes: can communities, the municipality and smart utility providers work together to build a platform for the community? Let us first define the platform.

2.1. Platform definition

We will describe the platform by explaining its system architecture and by discussing its sponsor, its providers, sides, economic utilities and network externalities, financial resources and policies. We will outline the strategies for how to position, present, realize and operate it. For a general discussion of platforms and platform businesses, see [8].

A smart community wireless platform is a community wireless network built and maintained through collaboration of the community, the municipality and the smart service providers. There are multiple sides on this platform: (1) users who use the wireless network and they may also sponsor bandwidth, (2) bandwidth sponsors who sponsor bandwidth for this wireless network, particularly the businesses, (3) other smart service providers.

In this model, the community and municipality assume the main roles. The amount of involvement varies in realizations of this model in different cities and even within different communities in the same city. Municipality plays an important role in this platform in both supporting the communities and organizing them to participate into the city-wide bigger wireless network.

The users are community members or visitors that use the wireless network.

Bandwidth sponsors are entities that sponsor bandwidth used by the users to connect to the Internet. Community members may be users and bandwidth sponsors at the same time. Businesses, non-profits and organizations in the community become bandwidth sponsors. Smart service providers may become bandwidth sponsors. In this paper, we will focus more on businesses as the bandwidth sponsors that provide bandwidth for the users.

Smart service providers offer smart services to the users of the platform. One typical example is the utility provider companies like electricity, gas, water, waste management. For example, waste management company provides services for smart garbage collection to the users of the platform. We will not use the term utility for them (as in electricity, water, gas) in this paper as we will use the term utility to refer to economical utility for being on the platform. We will call them as smart service providers. These smart service providers use the community wireless network for communication of their smart devices (sensors, smart devices, and other IoT devices) that they place in the network. They benefit from the platform by placing IoT devices that use the wireless network for communication, or more likely by building sensor networks that integrate with the wireless network. They sponsor bandwidth so they become bandwidth sponsors and they may provide other components into the platform as explained in later sections.

Another example to smart service providers is the city offices and department. For example, parks department provides services for park resources. Another example is the community itself in providing smart services to its members, for example, smart education services.

2.2. System architecture

Figure 1 shows the layered system architecture for the platform. It has the following layers:

Smart Community Wireless Network Layer: Wireless network is built on top of the wireline infrastructure that has network nodes, servers and cabling provided by community, municipality and smart service providers.

Middleware, Data and Infra Layer: Computing and storage infrastructures belonging to the community, municipality, and smart service providers in this system store data and offer computing, networking, caching and data storage resources. It contains software platforms and services including middleware, service oriented solutions, fog and cloud computing infrastructures (both commercial and community clouds). Other components include reliability, security, privacy and trust solutions. Infrastructure offered by smart service providers hosts the data and resources for smart services. Those infrastructures could be accessible through the wireless network. Given the complexity of the smart services and the extent of the data generated by the platform sides, this layer should be capable of storing and processing the data. It should be able to store and process various types of data including events,

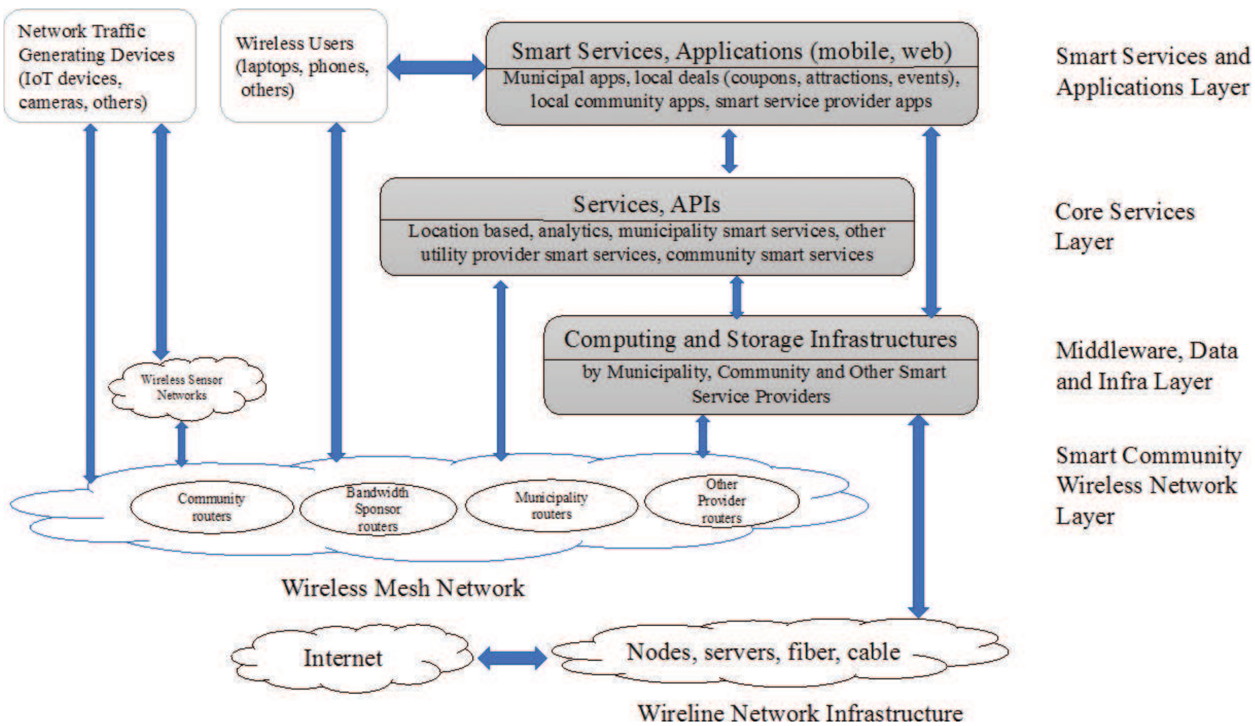

Figure 1. System architecture for smart community wireless platform.

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unstructured, structured, geo-spatial, crowdsourcing data. The smart service provider infrastructures may be required to perform real-time processing.

Core Services Layer: Some core services such as analytics, user location tracking, location-based services, search, semantics, context processing, visualization, collaboration platforms, geo-spatial services, access to public data and statistics, community social networking and other digital community services are offered using this infrastructure which is accessible by the wireless network. Outputs of data analytics and mining are offered at this layer. These core services are usually accessible to bandwidth sponsors and smart service providers.

Smart Services and Applications Layer: This layer includes all smart services offered by the smart service providers such as smart transportation, smart health and smart government services. This layer offers APIs of the smart services for application builders. Additionally, it includes mobile and web user applications offered by municipality, community and smart service providers.

Wireless users and IoT devices use the wireless network and generate network traffic. IoT devices belong to the smart service providers that participate in this platform. They are usually part of wireless sensor networks but can be directly connected to the community wireless networks. Network traffic from some of the IoT devices would not leave to the Internet, but rather stored, processed and analyzed in the infrastructure accessible by the community wireless network.

With this architecture, various services can be offered in a modern smart community. All these services are provided by smart service providers (e.g. private companies, municipal offices and communities). The platform creates an ecosystem around this system architecture. This architecture hosts an internet of everything environment including connected devices, users, communities offering community services, smart service providers using the network and offering their smart services.

The smart service providers are vertically integrated to provide their services over the platform. Some of these services are available only on this platform. The providers use the wireless network for collecting data from field devices into their infrastructures and may offer the same services over the Internet, which can be accessed by anyone. In any case, the wireless platform provides a home for the devices and for collecting their data. The providers contribute to this network by supplying access point routers that connect their devices to the wireless network and preferably by sponsoring additional bandwidth.

Internet access is supplied by bandwidth sponsors and commercial ISP services.

We will not present a detailed design of the wireless network in this paper, rather we will state our assumption. We assume the platform uses a mesh Wi-Fi technology as it is most often the technology used in such networks. In the network, there are access points and routers supplied by the community usually having generic server hardware and running open source firmware and software. The mesh network usually runs open source mesh network routing software and open source network management software to setup and manage a software-defined wireless mesh network. In addition to routers supplied by the community, there are routers supplied by the community members and other routers belonging to municipality, to the sponsors of bandwidth and to the smart service providers. The design should cover the whole target area by adding intermediary routers in places where no sponsor router is available and should be able to redirect user traffic to any of the available access points.

The platform relies on community members, businesses and organizations to share a portion of the total required bandwidth to access the Internet. So, a significant assumption is that ISPs allow plan sharing in their service terms. When bandwidth sharing does not supply the required bandwidth completely, remaining bandwidth needs to be purchased from the local commercial ISPs.

The mesh Wi-Fi network uses mechanisms for access control, metering and blocking the user traffic beyond a daily cap. It enforces rate limiting of the users with respect to data rate and the amount of download/upload. It employs self-adjusting network functionalities for fairness such as enforcing dynamic rate limiting the bandwidth to each wireless interface based on the current total number of users. When the number of users exceeds the network capacity based on minimum bandwidth for each device, new connection requests are not granted thanks to dynamic connection admission control. Therefore, some users will be blocked and not able to join. The city officials and municipal services have guaranteed service for accessing the wireless network, and they are not blocked.

The wireless network should offer enough bandwidth to fulfill the basic requirements of the users and support applications that will benefit the community and the city. Such applications include community social networking, community calendar of events and information about events, services offered by community, municipality and commercial smart service provider's offer. On the other hand, it should not be positioned as a competitor to commercial cellular or wireless networks as we argue in Strategies For Platform Promotion and Positioning section. For example, it should not allow unlimited upload and download. One option is to rate limit the download/upload speeds. Another option is to limit the traffic to and from the Internet while the users could enjoy unlimited access to the smart services. In other words, their Internet traffic is metered and capped, however, traffic within the wireless network could be unlimited, or limited with a higher cap subject to the whole capacity of the wireless network.

The wireless network implements typical security and access control mechanisms [9, 10].

When similar networks are integrated together, a seamless network covering a bigger span of the city could be possible [5].

2.3. Platform control

For the platform, it makes sense for the community to be the platform sponsor and the primary provider. Community has the say on management and policies of the network. The community decides on what policies and what strategies to apply. In another arrangement model, municipality and community may behave as the platform sponsors, but we will assume the community is the main sponsor and provider of this platform in this paper.

We assume no commercial offerings using this platform by municipality due to existing state laws. We assume the community does not engage in seeking any profit using the platform. The platform is not commercial and is not for profit for the community. For this reason, many of the concerns applicable to commercial platforms do not apply, like pricing but some other concerns apply like funding. We assume the platform will be free for users but possibly with some volunteering or sponsoring bandwidth in return, or with agreeing the usage terms and giving up some privacy.

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The term sponsor is used in two meanings in this paper and they should not be confused: one in the meaning of platform sponsor which is the entities that control the platform. The other one is the bandwidth sponsor, for example, businesses that provide bandwidth for the wireless users to connect to the Internet.

Community mainly supplies volunteers and bandwidth sponsors. Municipality helps by allowing the community to use city owned light posts, traffic lights and municipal buildings for attaching access points, and by allowing to use wireline infrastructure; assisting the grant writers with grant applications; providing access to GIS mapping data; assisting with network design; financial help by identifying grants and tax breaks for community networks. With community and municipality working together, businesses and other smart service providers would join the bandwagon increasing the network externalities and adding value for the platform, therefore making it a viable platform.

The openness of the community wireless network is controlled by the community. Normally, the platform is open to any user provided they accept the usage policies. The community will decide on the criteria for who can join as developer and providers of services and on what conditions. The community decides whether the wireless network and infrastructures are open to any developer to develop some service/application, or to any smart service provider to install devices and provide services. The community will decide if research tools can be deployed by universities, or by local startup companies. The community controls the quality of the wireless network and the services offered on it. The community decides and governs what complements such as location tracking and analytics can be provided and by whom. The community makes these decisions following their decision making methodology, for example, may perform SWOT analysis for the complement providers and smart service providers. The complement providers could be commercial ISPs to sell bandwidth, other providers of the equipment, software, services and know-how.

2.4. Utilities and network effects

Each side of the platform has an intrinsic utility for being on the platform. For example, users have utility with being on this platform in the form of getting wireless service and additionally by receiving coupons, deals and other location-based offers, and accessing smart services. Businesses have utility for promoting and advertising their businesses. Similarly for the municipality and other smart service providers.

In addition to the intrinsic utility, each side experiences additional utility due to network externalities. Network effects exist impacting the utility of different sides for being on this platform. It is assumed that the user utility and network size would follow a logistic ("S"-shaped) function. Same side effects will help increase the user population thanks to information diffusion initially. Increase in population would later negatively impact the utility due to congestion, possible degradation in the quality of the wireless network and being blocked in the shortage of available bandwidth.

Cross side network effects exist. There could be positive network externality between users and bandwidth sponsors. Similarly between users and smart service providers. Policies and strategies would increase the network effects and thereby the utility of different sides. We will discuss some policies and strategies for taking advantage of the network externalities in subsequent sections. Network effects are so many and will be outlined in later sections.

2.5. Platform evolution

The community should exercise policies that will allow users, community members, component providers to offer ideas and contributions. The platform evolves by being open to community needs, fostering innovation by allowing community startups and pilot projects and university research and being a testbed for innovation. The use of open source supports such collaboration between global developers and the community developers. Collaboration among communities and tracking what other communities do will help evolve the platform into new technologies and approaches. The community should be transparent to the users about the evolution of the platform as to provide more accurate information about the future roadmap and shape the user expectations accordingly.

The community needs to monitor the total payoff and estimate the lifetime customer value (LCV) and a new user's impact on existing users' utility. Based on these, the community should find the optimum number of users the wireless network should support before considering investment for updates, upgrades and expansions. Therefore, there will be blocked users.

2.6. Financial resources

The smart community wireless platform reduces the financial responsibility for the city, but funding is still required. The municipality could continuously track and search for funding and try to maximize the amount of funding collected for the community platforms. For each grant, the municipality could maintain the area, the purpose, the conditions and constraints of the grant. Certain grants are given for specific applications and purposes (e.g. safety, energy, climate preparedness, transportation, health) and by different sources (e.g. by the Department of Homeland Security, Department of Transportation, Department of Energy, Department of Commerce, and the Environmental Protection Agency). Although many funding opportunities and sources exist, different communities may focus on different ones based on how the opportunities fit their needs and objectives. The community also should be on the look for funding sources by mobilizing its volunteers.

Funding sources include grants, tax benefits, donations (from local organizations, businesses, and community members), bandwidth sponsorships, new exploratory research funds, new hackathon challenges and awards, free services from companies (e.g. free cloud service), testbeds (for trials of different technologies, ideas, models), special funds (e.g. system and service for first responding by department of homeland security), and crowdfunding opportunities [3–5].

2.7. Policies

What should be the ownership, maintenance, and security policy for the platform? It is expected that the community owns the platform as being the sponsor. Regarding maintenance policy, it is expected the community maintains the network with the help of volunteers and part-time contractors.

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Who should do the authentication and authorization of users? What should be the user privacy policies? For this platform, the community should control authentication and authorization policies. The users would have to give up on some of their privacy by entering their profile (e.g. via a survey at first login) and agreeing for being tracked for usage and for location. This information is used for analytics and improving the wireless experience, and is integrated into the loyalty programs and deals of the sponsoring businesses. The information is shared with the sponsoring businesses, which is an incentive to bring in more businesses and increasing their utilities. Additionally, this information is used to trace individuals in case of any illegal online activity on the network.

2.8. Strategies for increasing utility of platform sides

Strategies should be developed and employed to increase the value of the platform for different sides and to reach the critical mass in terms of regular users within the community and by visitors. These include strategies to mobilize the volunteers, officials, sponsors, non-profits, smart service providers, commercial ISPs, component and complement providers. There should be strategies in place for:

- Bringing in users by offering them a consistent service as well as access to business loyalty programs and smart services over the platform.
- Convincing private investment for upgrading the broadband infrastructure. Strategies for private investment to lay down more fiber, upgrade wireline infrastructure and services, improve wireless coverage and employ latest technology should be in place.
- Motivating city universities for research and development to help with technical and managerial initiatives. Provide them opportunity to test ideas, provide them with testbeds, nourish their business and management ideas.
- Bringing in other organizations (e.g. non-profits): they will not have much utility for offering their bandwidth just so that more people visit an economic district, but would have increased utility with contributing to the community in developing areas and for reducing digital divide.
- Bringing in smart service providers such as smart parking and waste management.
- Effective crowdsourcing and crowdfunding
- Convincing ISPs to allow sharing the broadband connection.
- Convincing businesses to sponsor by presenting how the platform could lead to more customers, by allowing them to advertise and do directed marketing by accessing the user data, tracking data and analytics on them.
- Convincing smart service providers to sponsor bandwidth in addition to the bandwidth they should provide for their IoT devices.
- Convincing users to sponsor bandwidth: the user is expected to share bandwidth to be able to utilize the network beyond a cap. This option is effective in a residential community, not in a business community where users are mostly visitors.

In residential areas, a crowdsourcing strategy could be employed for residents to join the wireless network and contribute from their broadband connection [3, 15]. The same strategy would not work in a business district. Rather, a strategy that increases utility of the bandwidth sponsoring businesses and non-profits in the area would be more effective.

2.9. Strategies for platform promotion and positioning

Other strategies include positioning the platform, its launch and promotion. What strategy should the municipality follow while helping community mesh wireless and rolling the smart city services on this network, and meanwhile encouraging private investment? Municipality and communities must appreciate the value of commercial investment in the city, should stay away from any policy or strategy that will deter them. The platform should not be positioned to compete against commercial wireless services and substitutable offerings. It should not be about being a winner in the market. Rather, it should be for serving a real need in the community for a specific purpose and to fill the gap from commercial providers. All policies and strategies should be compliant with these principals, that is, keeping the availability of substitutable and commercial offerings. Otherwise, the platform could deter private investment. Additionally, the city may run into legal issues as happened in earlier attempts [2]. Policies and strategies should encourage broadband modernization by private industry both in wireline (fiber) and wireless (5G). On the other hand, community and municipality could try to convince the local incumbent ISPs to lower prices and alter terms of service agreements as this happens with community networks by grassroots groups [1]. In our opinion, this platform should not be positioned as an alternative to conventional ISPs in the last mile, rather a balance should be preserved so that commercial ISPs still find interest and profit in the community. As an example for not competing against substitutable offerings, the bandwidth in the community wireless network should be limited to basic use so that commercial providers still find interest in providing better quality services for fee.

3. Intelligence framework

One important question is how much would be the total cost of building and operating such a platform. Another question is how to measure the benefits and drawbacks to estimate the returns on investment over a period. Another question is how to model risks and mitigation plans for the success. One objective of this paper is to examine relevant dynamics in estimating the total cost of these platforms and develop a model for estimating the cost under various conditions and scenarios. Another objective is to examine relevant dynamics in estimating the benefits, drawbacks and risks and develop models for measuring them. We address these objectives by using an intelligence framework.

In our earlier work [11], we used an intelligence framework for analyzing platforms in general. We will use the same intelligence framework for analyzing the smart community wireless platform with some additional analysis and decision making techniques. Our framework incorporates developing system dynamics (SD) models together with use of economical, statistical and machine learning models. SD modeling and statistical methods have been used for analyzing municipal wireless networks in earlier work [2, 6, 7]. SD modeling in general is used for understanding and analyzing business and management related issues such as estimating cost, benefits and return on investment, and risk analysis. To estimate the total cost over a period, simulation is a powerful tool to try out different scenarios. When detailed statistical analysis could not be done due to shortage of data and exact understanding of how the system works, SD models involving hypothesized assumptions can be valuable tools to demonstrate expected impact of various business decisions when there are feedback relationships among the involved dynamics. With SD model, one can also model the network effects among different sides of the platform and model how the economical utilities due to network effects behave. In our intelligence framework, estimation is done by building SD models together with economical, statistical and machine learning models, running simulations and performing sensitivity analysis. Qualitative SD approach improves system understanding and prediction for various scenarios, even in the absence of quantitative data. This framework has been used in [11–14].

Three are many variables used in the intelligence framework. For the cost and benefit models we develop in this paper, we describe the dynamics and their relevant variables in later sections. Application of this framework into various problem domains requires utilizing additional analysis and decision making techniques and approaches. The problem domain of community wireless network design requires us to further employ the following tools and methods into our intelligence framework:

1. The use of GIS data and mapping techniques for asset mapping and geographic area characterizations while planning and designing the wireless network.
2. The use of network design simulators to estimate needed bandwidth based on expected number of users, expected applications and their QoS requirements like the response time, and for simulating the impact of content caching, location tracking, IoT traffic.
3. The use of tools and models for wireless network security analysis and assessment.

In this section, we will outline how GIS mapping and network simulation exercises would be used in the wireless network design which correspond to the first two items above. Security analysis and assessment related data will not be discussed.

3.1. GIS data and techniques

As the platform relies on community sponsors, all potential assets should be identified and mapped using GIS tools. The assets include bandwidth sponsors such as businesses, hospitals, community based organizations, libraries, schools, religious organizations. These should be reached to find out if they would like to participate in the platform as bandwidth sponsors. They could be classified into three groups like large, medium and small bandwidth providers and mapped in different colors in GIS.

The assets also include the city light posts, buildings, municipal facilities and other physical infrastructure for attaching the equipment. Physical characteristics such as terrain, elevation and alternate infrastructure should be taken into consideration in the design as well as trees and buildings that may be barriers to line of sight between the access points.

Given the size of the area, expected population to use the wireless service, expected usage patterns, the bandwidth requirements of different sections in the area could be estimated and marked in GIS in different colors. Based on needed bandwidth in different sections, how many root access points and where to place them could be designed. In general, root access points should be positioned close to large bandwidth sponsors. After placing the root access points, other equipment mainly the mesh access points are placed in GIS. This is done based on assumed range of the mesh access routers and recommended number of mesh access points per root access point. The distance between the nodes might vary based on the distractions in line of sight between nodes. It would be helpful to draw circles around the nodes for representing their coverage.

This exercise helps with estimating the number of root access points and mesh access points. It shows in GIS where enough bandwidth is being sponsored and where additional bandwidth is to be purchased. It helps with estimating how much bandwidth is to be purchased. Additionally, it shows which sections of the area are well covered and which sections do not have enough wireless coverage.

This GIS mapping exercise addresses the usage by users only. The same exercise should be carried out with smart service providers for their IoT devices.

3.2. Network simulation

The network simulation exercise is to help with planning, logical designing, optimizing and reconciling the community wireless network design. The planning phase helps with developing an estimation for usage patterns and network traffic categorization. This exercise is done under the assumptions of the objectives of the community and together with the GIS mapping exercise.

The logical design phase is about creating a logical design that represents the basic building blocks and the structure of the network. This high-level design considers options for how and where to connect the wireless network to the Internet. This is done also together with the GIS mapping exercise. The high-level topology of the network is logically designed for further simulation purposes. A hierarchical model having core, distribution and access layers is common for the high-level topology. The core layer abstracts the wireline infrastructure including backhaul nodes, fixed routers, cabling and dedicated Internet connections. The distribution layer contains the root access points. The access layer contains the mesh access points and the user devices. The logical design is used in simulations to estimate QoS performance and availability measures. This function is complex and requires building network simulation models and running them to compare wireless network and infrastructure performance. However, traffic simulation is worth the effort as it can result in tangible benefits such as studying the need for content caching in the community network to reduce traffic to/from the Internet, estimating the impact of network security features, and modeling the impact of different wireless network policies.

The reconciling phase brings together the simulation results against the objectives and cost constraints. This help the platform providers to re-evaluate the objectives and assumptions on the platform, to re-think about the hypothesis and to more clearly see the inefficiencies or flaws in initial estimations.

This network simulation exercise addresses the usage by users only. The same exercise should be carried out with smart service providers for their IoT devices.

4. Developing models for cost estimation

In this section, we focus on SD models for estimating the initial and maintenance costs.

4.1. Methodology for developing cost models

We suggest a methodology for developing cost models. The methodology suggests:

1. Work out the characteristics of various cost related dynamics which will be needed in simulation and decision making. These dynamics should be elaborated for a specific community platform through the activities of needs assessment, resources analysis, partnership analysis, asset mapping, network/security/operations planning, policy development. These are done best by the community itself, as the community leaders, volunteers, stakeholders are most aware of the needs, resources and capabilities.

2. Once conceptual dynamics are characterized and cost related variables in those dynamics are identified, these dynamics are incorporated into SD models for estimating the cost. Characterization of several dynamics including financial resources, policies, strategies and utilities are outlined in earlier sections. We will characterize additional dynamics together with cost related variables in the subsequent sections.

3. With data collected during planning, development and operational phases of the wireless platform, build and fine tune the statistical, economical and machine learning models, integrate them with SD models, validate and fine tune the SD models.

In this paper, we will apply the first two steps above.

4.2. Community characteristics

The exercise for characterizing the community should yield values for the following:

- How big the community and how many different potential service areas exist
- How much volunteering from community: How big the volunteer groups (for setup, for maintenance activities, for security and customer service requests)
- The amount of community help for finding grants, needs assessments, publicity and promotion, setup and installation, integration
- How successful the crowdsourcing could potentially be in the community
- Community effectiveness for implementing the strategies for bringing in bandwidth sponsors and smart service providers
- Community help for finding sponsorship and its effectiveness for convincing partners

- Availability of technical skills in the community
- Community effectiveness for developing technical solutions for the wireless network

4.3. Service area characteristics

A community is part of the city like a neighborhood. A service area is an area/district within a community. Our assumption is that there could be multiple service areas within a community and each service area could be different. For example, one service area could be a business district with economic development objective, whereas another one could be a residential district with objective of reducing the digital divide. Where the community has different service areas with different characteristics, it makes sense to characterize service areas separately. A community wireless platform becomes the union of possibly several wireless networks in different service areas with different dynamics.

The exercise for characterizing the service area should yield values for the following:

Demographics related: Population move in, move out and growth rates. Population during day, night. Resident population, visitor population.

Businesses related: Number of businesses willing to share bandwidth and how much bandwidth they will share. Social responsibility awareness scale of businesses in the area.

Substitutable offerings related: Availability and quality of cellular services and hotspots.

Setup related: Size of the area. Availability of city light posts, buildings, municipal facilities and other physical infrastructure for attaching the equipment. Existing IT and networking infrastructure like fiber, municipal IT resources, smart service provider resources. Other geographic and dwelling factors (building, roads, rights of ways) that will impact the setup.

Attractiveness related: Service area attractiveness for grants, sponsorships, donations. Attractiveness for the visitors including shops, places, accommodations. Social initiatives and public services that will impact attractiveness.

Usage related: Projected initial usage characteristics and demand: How many residents will use the system? How many visitors will use the system? What percentage of users use how many times, when and how long? What types of digital activities do community members often perform on wireless network? Peak hour characteristics of the usage? What smart services are available in the platform?

4.4. Municipality characteristics

The exercise for characterizing the municipality should provide values for the following:

- The extend of municipality help with allowing to use traffic lights, light posts, municipal buildings in the community. IT infrastructure elements such as cache servers the municipality could provide to the community.

- Municipality help with grant finding and preparing applications to grants
- Municipality help with launch, publicity and promotion
- Municipality help with network design, setup, installation and integration
- Municipality help with ongoing operations: help with security admin
- Municipality help with training people maintaining the network and the volunteers

4.5. Wireless network and infrastructure characteristics

The exercise for characterizing the wireless network and infrastructure should provide values for the following:

- Characterization of the wireless mesh network: total available bandwidth, overall throughput, latency averaged over all APs based on the design of the mesh network. Availability and reliability of the network. Overall security score of the network. The number of APs in the mesh. How many users can be supported at maximum.
- Characterization of the wireline network: similar to that of the wireless mesh network.
- Characterization of the computing and storage infrastructures: latency and throughput for typical use case transactions. Number of transactions per second per use case.

4.6. Online services and applications characteristics

The number, availability and quality of services in the area increase the utility for users and sponsors. We characterize the services in terms of their availability and quality, and bandwidth demands. These are needed for estimating:

1. Projected application and bandwidth characteristics
2. Attractiveness of the service area to visitors

The exercise for characterizing online services and applications should provide values for:

What services offered to users: Online services from the municipality offered in the service area (for safety, security, municipal services). Services provided by smart service providers. Location-based services using wireless network and IoT beacons for coupons and loyalty programs in business districts. Community online services such as community social network, community cloud. Community virtual visitor app that highlights locations, attractions, points of interest, events, local deals.

Availability and quality of the services: Estimated initial values for these and real monitored/observed values when the services are operational.

Bandwidth demand: Expected number of users for offered services in the area, initially estimated but later monitored. How much data traffic is generated within the wireless network. How much traffic is to be transmitted outside of wireless network without using the

Internet but using network infrastructures supplied by municipality or other smart service providers. How much traffic will be transmitted to the Internet. For example, security cameras feed data traffic into wireless network and wireline infrastructure. This data mostly remains within the network and not need to go to the Internet or other networks. On the other hand, vehicle traffic monitoring cameras feed data into wireless network and this data may go to other networks over infrastructure and streamed to the Internet possibly via separate ISP connections.

4.7. Smart service providers characteristics

Smart service providers place sensors and other devices into the wireless network. They use these devices for their own purposes and they also offer smart applications (e.g. waste monitoring). One characterization is to figure out the amount of data traffic their devices will generate within the wireless network: the traffic transmitted over the networking infrastructure till the data reach the local infrastructure of the smart service provider and/or used by the users on the platform, or reaches the private network connection of the smart service provider. The amount of Internet traffic used by their devices.

Another characterization is for finding out the amount of bandwidth they will sponsor. This amount should be equal or higher than the bandwidth generated by their devices and users. There are two types of bandwidth they need to sponsor: one for the wireless network and the infrastructure for data to remain in the network, and the other one for the Internet. For the infrastructure, the smart service provider should contribute APs into the mesh network. For the internet, the smart service provider should sponsor at least enough bandwidth for their own Internet traffic. Smart service provider may have dedicated connection from the wireless network to their data centers for transmitting IoT data. It is assumed that the smart service providers have their own Internet connectivity from their data centers.

4.8. Quality and attractiveness of wireless network characteristics

Initial attractiveness of the wireless network mostly depends on service launch strategy. Ongoing attractiveness depends on:

- How municipality and community promote and advertise the network
- How they incentivize the citizens to use the network
- The quality of the wireless service with respect to QoS (availability, bandwidth for each Wi-Fi interface, throughput, latency)
- Availability and quality of substitutable offerings such as hotspots and cellular services
- Quality of customer service for security and other usage tickets
- How the network evolves in response to changing usage characteristics: an analytic roadmap is needed to monitor the patterns and re-engineer the network accordingly.

5. SD models for cost estimation

In this section, we develop SD models taking into consideration the cost related dynamics and variables. We consider a service area with economic development objectives in a business district. Since our focus in this SD model is economic development for a business district, the model we present may not apply directly for residential areas.

5.1. Initial setup cost estimation

Figure 2 shows a simple linear SD model with no feedback loop for initial cost estimation for a single service area. It is simple and linear as there is no economic utility to calculate nor any network effect to incorporate.

Cost variables include: Needs assessment fixed cost, Cost of needs assessment, Grant application fixed cost, Cost of grant application, Net from the grants, Raising donations fixed cost, Cost of raising donations, Net from donations, Sponsorship raising fixed cost, Cost of raising sponsorship, Cost of launch, publicity and advertisement, Network design cost, Equipment and software cost, Setup and installation cost, Integration cost.

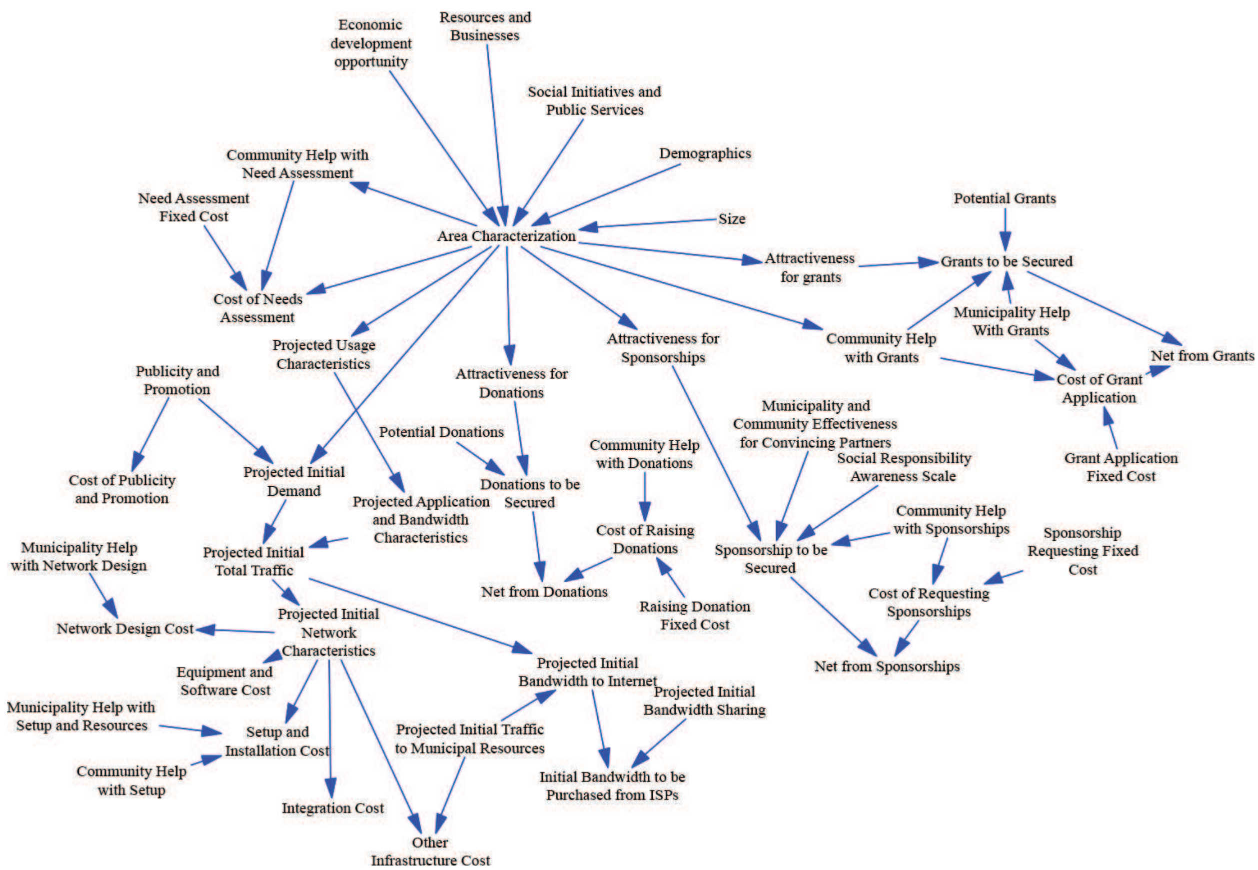

Figure 2. SD model for initial setup cost.

Using this model, total cost and total deductions are easily calculated. Percentages of each cost item with respect to total cost are calculated. The budget can be compared to the final cost. The net present values can be easily calculated with proper formulation.

Initial demand is estimated in the model which is characterized by:

1. Projected initial total traffic
2. Projected initial traffic to wireless network, the underlying wireline network and the IT infrastructure
3. Projected initial traffic to the Internet
4. Projected initial bandwidth sharing (sponsored by the sponsors): This value is provided as an estimate into the model. This value is estimated from service area characteristics in a separate SD model and fed into this model as a variable.
5. Projected initial bandwidth to be purchased from ISP

Economic development opportunity variable was not included in the characterization since it is not applicable for all service areas, but applicable to service areas with business development objectives such as business districts. It indicates how much economic development opportunity exists in the service area and is one of the variables used to determine the size and coverage of the wireless network. If there is not much opportunity, then no big investment will flow into the network and therefore no big wireless network.

Although initial setup cost estimation could be done with a simple spreadsheet model, SD modeling is still useful for visualizing different cost components and how they are related. It is also helpful to run sensitivity analysis on how different scenarios impact the cost and for estimating the cost spanning over the duration of the setup of the wireless network. Sensitivity analysis could estimate the total cost along with other variables in different scenarios with different size of the service area, amounts of community volunteering, municipality help, grants, involvement and sponsorship from businesses, and with varying levels of success in crowdfunding and crowdsourcing, and with varying cost components such as equipment, setup cost, consultancy cost. It would be easy to see if the setup cost is within the budget under what combinations of other variables. Decision makers could use sensitivity analysis to balance various variables to achieve the cost objectives.

5.2. Maintenance cost estimation

Maintenance cost includes ongoing capital expenses and ongoing operational costs. The first is due to upgrades in response to increased demand and better understanding of usage characteristics. The second one includes costs for bandwidth, electricity, contractors, equipment maintenance.

Figure 3 shows an SD model for estimating the total maintenance cost. This model has feedback loops and non-linear relations where the advantages of SD can be realized more compared to the model in **Figure 2**. The model does not show all the variables, rather it shows the different characteristics for simplicity. Variables exist within the characteristics in the model as per characterizations outlined in earlier sections.

Users in this model are classified into PotentialUsers, Users, Quitters and BlockedUsers. The first three are measured as stock variables in the SD model and are related to the adoption of the wireless network by users. There will be blocked users and that is expected by design as explained earlier. An ongoing evaluation of the performance of the wireless network using various measurement tools should help the decision makers if it is up for upgrades.

The number of potential users may change based on demographics, economic, or other factors as well as consumer behavior. Potential users adopt based on not only the intrinsic utility but also on expectation of future utility. Similarly for the churn of existing adopters. Network externalities play an important role on the utility in addition to the intrinsic utility from the wireless network itself. The utility of the service for the user depends on interconnections among the users and utility they receive from the other sides of the platform. Existing users may become quitters depending on their patience levels due to low service quality and poor customer service. Quitters may become adopters based on the come-back fraction variable which is set a value based on the expected future utility.

One important variable is area attractiveness. This depends on many factors. It is one of the factors that attracts new users or leads them to Quitters stock. It is influenced by the number of users. So, there are positive and negative loops between the attractiveness and the number of users yielding an s-shaped curve. Area attractiveness has similar relationship with

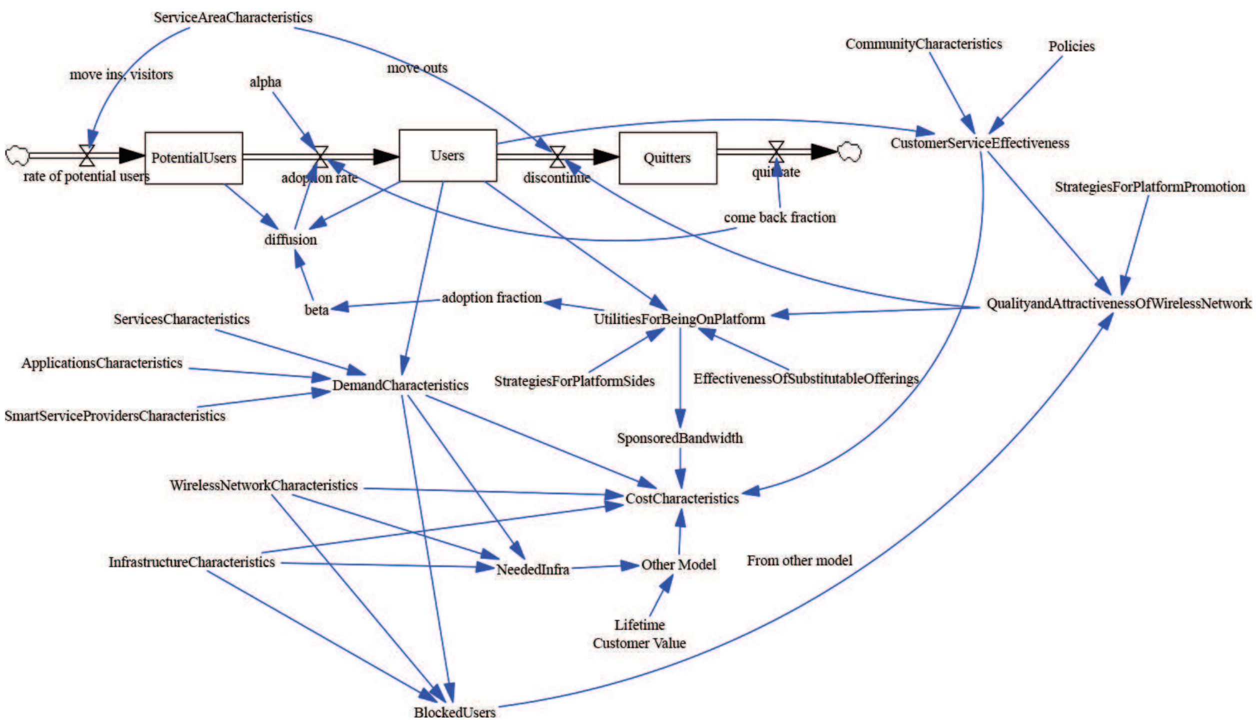

Figure 3. SD model for maintenance and operation cost.

bandwidth sponsoring, yielding again s-shaped curve. The model does not show a stock variable for area attractiveness. It is retrieved from the Service area characteristics variable. A separate SD model measures the area attractiveness as a stock variable.

Utilities for being on platform has a separate economic utility variable for each side of the platform, that is, for users, bandwidth sponsors and smart service providers. Strategies for platfom sides includes assigned values for the effectiveness of considered strategies for increasing the utilities of platform sides. Sponsored bandwidth is an aggregation of all sponsored bandwidth from any side on the platform including users, businesses and smart service providers as they all could sponsor bandwidth. For business districts, the model assumes more bandwidth sharing by the local businesses.

Ongoing Demand Characteristics for this model includes total demand by users, bandwidth per user, demand for other smart service providers, bandwidth by IoT devices and wireless sensor networks, fraction of bandwidth from smart service providers to the Internet, total bandwidth in network, total bandwidth to the Internet, bandwidth to buy from ISPs. The amount of bandwidth sharing is to be calculated over the given period, e.g. 4 years. With this model, total cost for a unit period, e.g. each month, is estimated over a duration, e.g. 4 years. SD is good for this type of calculations for the reasons mentioned earlier.

Ongoing capital expenses in the total maintenance cost are the cost of needed upgrades and expansions to the wireless network and infrastructure. This cost is calculated similarly to calculating the cost of infrastructure in the linear Initial Setup Cost model in **Figure 2**.

Ongoing operational costs in the total maintenance cost include:

1. Cost of Customer Service: this relates to customer service effectiveness, mainly the cost of part-time admins and customer service representatives.
2. Cost of Bandwidth to Buy From ISPs: this is related to the difference between the sponsored bandwidth and the total bandwidth demand to the Internet over the period.
3. Electricity Cost: this is for all APs, nodes, servers and other equipment from Wireless Network Characteristics and Infrastructure Characteristics.
4. Device Maintenance Cost: this includes replacing and repairing the APs and other equipment subject to the availability of the devices, networks and infrastructures (but not including the IoT devices and sensor networks of smart service providers).

5.3. Different scenarios for cost

The model can be run for simulating different scenarios. With simulations and sensitivity analysis, this model could be a powerful tool to answer many questions. Not just estimations of various cost components, but also relations among other variables can be analyzed. Some questions to answer using this model include:

- How many users use the system and how that number changes over time. Similarly for blocked users and for uses who quit due to dissatisfaction.

- Can the network provide QoS (enough bandwidth) for different usage patterns?
- How the municipality role impacts the success with respect to achieving the number of users and keeping the cost within the budget.
- How the rollout strategy impacts the user adoption.
- How the maintenance and management policy impacts the user adoption.
- Is the maintenance cost within the budget?
- How much grant is needed?
- How much bandwidth from sponsors is needed?
- How different strategies for incentivizing different sides of the platform affect the cost.
- How different strategies for incentivizing the sponsors work?
- How the network effects are?
- How the utilities change with different strategies, with different numbers of users and blocked users, with different levels of customer service and quality of the wireless network. How all values change in response to service area characteristics particularly its attractiveness.

Various scenarios can be analyzed by sensitivity analysis. Different triggers may be programmed for different variables at certain intervals to see how the cost fluctuates over a period. Different statistical distributions may be used over time for different cost items and for the characterization of community, service area and municipality.

6. Developing models for estimating benefits, drawbacks and risks

A smart community wireless platform offers benefits to the platform sides. Every such platform is unique and offers unique benefits to the platform sides. Different platforms would be built with different objectives by different communities. The success of the platform is evaluated with respect to the objectives of the platform.

An exercise to be done early in the planning phase is to identify the objectives of the platform. However, there are challenges in doing so: What the objectives should be? What benefits are sought? What beneficiaries are considered? Some benefits to one side may not be as beneficial to another side. There could be conflicting interests from different platform sides and therefore network effects may not be all positive. There could be even conflicting interests within the same platform side, for example residential users vs. visitors, retail businesses vs. others, commercial smart service providers (waste management) vs. municipality smart services (smart parking).

There are also challenges with measuring the benefits: Some benefits are tangible, some are not. Some are short term, some are long term. Some are direct, some are indirect. Some will influence other benefits in positive way, some will do in negative way. What are the conceived benefits? How to measure if the platform provides the conceived benefits? How to define the success of the platform and how to measure the success? What are the risks for the success and how to mitigate them? How policies and strategies are related to the success? What are the drawbacks and how to limit them? How do the drawbacks, the risks, the policies and strategies, the mitigation plans impact the success?

To address these issues, we propose a methodology for developing models to be used for estimating and measuring benefits, drawbacks and risks. These models could be used by local government officials, communities and local smart service providers in decision making. For developing models, we suggest the following methodology:

1. First characterize the objectives, benefits, drawbacks, risks, mitigation plans, policies and strategies for a given service area or a community.
2. Based on these characterizations, characterize the service area and the community. Identify the dynamics involved and variables to be used in estimation.
3. Then follow the same intelligence framework for building models.
4. Use the models for simulations and sensitivity analysis in early decision making.
5. As more insights are obtained and more data is collected, build statistical, economical and machine learning models, integrate them with the SD models, validate and refine the SD models.
6. Continue simulations and sensitivity analysis using the refined models as they are valuable tools in estimating and deciding if the platform would be feasible for a longer term, and to apply which policies, strategies and mitigation plans for the success.

We start applying the methodology by characterizing the dynamics in subsections below.

6.1. Characterization of objectives

The common objectives for smart community wireless platforms are (1) offering public safety and city services in the community and civic engagement, (2) closing the digital divide, (3) convenient services for citizens and users by enhancing digital experience, (4) economic development [7]. The characteristics about the objectives should determine what objective(s) are most relevant and with what relative weights for the community.

6.2. Characterization of benefits

The platform offers benefits to different sides as we summarize below. The exercise for characterizing the benefits should provide values for the listed benefits below.

6.2.1. Benefits to users

Access to free wireless Internet for citizens: Provides citizens with Wi-Fi experience and location-based services. Citizens can access the Internet over their smartphone, tablet, and other computing devices when they are in public spaces and on the move. They have access to city information and city services anytime. A community app will help improve the digital experience of the citizens. They have access to smart services provided by the smart service providers over the platform. The number of smart services matters. The more the number of smart services, users are more likely to have higher utility with the platform. However, this number by itself is not sufficient to increase the utility of the users, the quality as well as the functionalities provided by the smart services are significant factors.

Access to free wireless Internet for visitors: Enhance the visitor's experience. Community app for visitors will enhance their visiting experience, for example, from parking to shopping and attractions.

6.2.2. Benefits to bandwidth sponsoring businesses

Will the platform lead to economic growth such as more businesses, revenues, jobs, transactions, wages? Businesses can do better targeted marketing thanks to analytics which would yield density/utilization at given time of day or day of week, people flows/footfall, time spent in the area, first time versus repeat visitors. Location-based services offer new insights about user behavior that can also be leveraged by local businesses/retailers to do better targeted offers. Businesses can operate and adjust (hours, number of employees) based on the location data. Businesses could take advantage of real-time analytics for prediction of repeat visitors as well as new visitors based on similarity, and can customize their marketing strategies. Shopping centers can boost footfall by enabling shoppers to stay connected to social networks and share their experiences. New startups may appear for example for offering smart services over the platform. Innovation is fostered through university collaborations and entrepreneurial engagement over the platform.

If businesses and organizations benefit from the platform, these same businesses may also give back. Larger businesses may provide bandwidth and others may act as root access sites and/or connection points. With such returns, positive network effects are realized.

6.2.3. Benefits to smart service providers

Smart service providers may benefit by connecting their wireless sensor networks and IoT devices with the wireless network. They can offer smart services for the community. Municipality is also a smart service provider and may place their IoT devices/networks like the commercial ones for smart environment monitoring, smart light and street management, weather monitoring, traffic monitoring, smart public safety. Benefits include reduced cost by using wireless network for delivering smart services and reducing cost of operations with smart technology. For example, a smart service provider would save by having access to almost real-time data of its devices. More benefits are realized when these platforms integrate to a larger smart city wireless platform [5].

6.2.4. Benefits to community and city

One conceived benefit is a safer community with police, fire, emergency medical response teams using the wireless network for safer streets and neighborhoods. This helps with public safety, incident response, law enforcement, and keeping stores safe from thieves.

Efficiency is expected to improve in delivering public services with municipality using the wireless network for their services and citizens accessing those services. This results in lower energy and maintenance costs as well as more revenue from city services for example with paid parking. The platform helps the city with better leveraging of existing assets, better traffic management, improved planning, better ROI and greater savings for city reinvestment. It helps the community economically by boosting economic growth and city prospects, and it may help with innovation. It helps with improved education for closing the digital divide and greater citizen compliance. It helps the communities to be greener and elegant with smart waste and trash management.

About the benefits listed above, some are measurable such as smart lighting by comparing the electricity cost. Others are harder to measure such as benefits of reducing digital divide, and are over long term. Some are direct for example bringing in more visitors. Some are indirect such as crime rate reduction and increase in quality education which are not just due to the existence of the wireless platform but other factors as well.

6.3. Characterization of drawbacks

The platform has some drawbacks. There are inherent difficulties with building the platform as well as operating it. The characterization of drawbacks should provide values for them which are summarize below.

6.3.1. Harm to private investment

One main positive outcome with this approach is that it does not lead to legality issues. This is because the platform is owned and sponsored by the community. In other approaches where the municipality owns the network, ISPs can sue cities for creating municipal wide Wi-Fi networks because cities would be competing with free market practices. In general, the city cannot monetarily benefit from a municipal wireless service in many states. Even with this model, the city should be careful in their policies and strategies on supporting the community platforms.

A risk with this model is it may distort the competitive markets and private investors. As a result, service providers feel discouraged from entering the market. Another risk is if the private investment may not update the cellular infrastructure in the community, but rather prioritize other communities that do not have such platform. On the contrary, this platform could lead the competing private commercial providers to enhance their services and offer higher quality services than the community wireless network and/or reduce their fees. The community wireless networks will produce more network traffic to/from the Internet and depend on ISPs enhancing their broadband services. When such community platforms are integrated to form a city-wide platform, the bigger platform can be used as a tool for bringing in more and diverse private investment. This is a subject we elaborate in [5].

6.3.2. Wireless network quality and availability issues

The wireless network and the infrastructures in **Figure 1** may not be as high quality as commercial offerings. How about the network problems, for example, access point or network element problems? Who will solve them? How about any customer service? Would the network be reliable and available and stable to run smart services? The availability of the network and

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the infrastructure may be less than adequate to run smart services. Similarly, the QoS supported may not be comparable to commercial wireless services.

Nonetheless, the platform should be positioned to support only non-critical services. Since this is a community wireless network, it does not necessarily cater for high performing and critical networked applications unless they are needed by the community and the community takes charge of supporting them.

As discussed in System Architecture section, the platform offers limited bandwidth for users and enforces a cap in total upload/download per period (e.g. day). Also, it enforces a limited number of connected users at any time. One risk is if it cannot attract enough sponsors over time to increase the limits. Another risk is the shortage of private investment to enhance the local broadband infrastructure and thereby the community network cannot have enough bandwidth to/from the Internet.

6.3.3. Security issues

Various security issues exist for this platform. As an example, hackers can create rogue wireless networks to lure the users into their network as opposed to the community wireless network. The platform should provide security guidelines for the users, and should monitor emergence of such rogue networks.

6.3.4. Drawbacks to the community

The sought benefits of the platform for the community may not be realized. Rather to the contrary, some drawbacks may appear. As an example, we can mention disruption to conventional way of life and businesses. This is due to embracing an all-digital life and isolating ourselves from traditional human interactions. Another drawback is increasing the digital divide. This happens when the platform becomes a playground for tech savvy but leave behind the other interest groups which are not very tech savvy [4].

6.3.5. Drawbacks to users

One drawback to the users with this platform is the privacy. Users give up on their privacy in return to getting free wireless service. Other drawbacks include limited bandwidth, low quality and security issues in the wireless network during use. Another drawback is the limit in total supported users at a time, which could block some users. Offering less than adequate customer service is another drawback.

6.3.6. Management issues

This platform relies on joint efforts from the municipality and the community. What happens when the community disagrees on the objectives and policies. There could be conflicting interests within the community about the objectives of the wireless platform. Policies are hard to agree upon and implement. Voluntary nature of most tasks may lead to slow progress on the development and inefficiency on the operations.

6.3.7. Financial issues

This platform relies on various funding sources. If funding cannot be granted, the platform may degrade and may not serve its objectives and may be abandoned by the sides, and eventually by the sponsors. This would result in a failed project and wasted resources.

6.4. Characterization of risks

The community decides on what level of risks to accept and what mitigation plans to consider and strategize. Most drawbacks outlined in the Characterization of Drawbacks section are risks that need to be managed. We can categorize types of risks as follows:

1. Risks of hitting the drawbacks above
2. Risks with the development of the platform
   a. Risk not getting enough help from the municipality
   b. Risk of political change in the city, disagreements between the municipality and the community
   c. Risk of project falling apart due to management and policy reasons, conflicting interests within community
   d. Slow progress due to bureaucracy and volunteering
3. Risks during operations
   a. Quality issues not handled
   b. Sides losing interest
   c. Not enough benefits realized
   d. Community not becoming part of smart city wireless platform [5].
4. Risk of pushing out private investment

The exercise for characterizing the risk should provide values for the levels of risks.

One risk is when the community does not get enough help from the municipality as the platform relies on municipality for various help including help with funding resources. Another risk is if the perception changes with political change by a new city administration and if the new administration does not consider the community platforms a priority. This will leave communities without help from the municipality. Another risk is that the progress may be slowed by political maneuvering and complex coordination processes. Another risk is conflicting views between municipality and the community. This relates to defining roles and the operational policy for preventing conflict between community and municipality. Conflict may lead to a risk of community not being part of the bigger smart city wireless platform or leaving it [5].

One risk is when the community cannot secure enough funding for building a platform even at a small scale.

One risk is when stakeholders, particularly bandwidth sharing entities, may not feel incentivized to bandwidth sharing. If the community does not have access to shared bandwidth, the cost of the network increases dramatically. Businesses such as hotels, shopping malls/centers have their own wireless networks and loyalty programs. Why should they be part of the platform? The benefits should be explained well to the businesses. This depends on effectiveness of community for convincing the partners. There is risk with sustainability due to lack of sufficient funds for maintenance and upgrades, and low adoption by intended beneficiaries.

There is risk of cellular providers not improving the service or not updating to latest technology if the mesh networks become widespread in the city. Another risk is wireless hotspot providers may end their services due to community wireless network. To mitigate these risks, the community should not build the network to compete against commercial providers as outlined in Strategies For Platform Promotion and Positioning section.

Another risk is with causing divides in the community, for example between geeks and non-geeks when tech savvy members controlling the platforms and others are falling behind. As a mitigation, the community should seek inclusion of all, not just the tech savvy.

6.5. Characterization of success

The success of the platform is evaluated with respect to its objectives. One success factor is how the economic utilities of the platform sides increase. Others include:

- How policies and strategies are contributing positively toward the objectives
- How the benefits are realized, how the cost is kept to minimum with grants and crowdunding
- Whether the objectives were really the right ones, or unachievable or unrealistic or unbeneficial objectives were pursued

One success indicator is the ratio of sponsored bandwidth to total bandwidth, which is an indicator to effectiveness of the community in getting bandwidth sponsors on the platform. Performance related success criteria include QoS, reliability and availability measures of the network, time to respond to tickets, whether the network can support maximum number of non-blocked users with predictable QoS. The exercise for characterizing the success should provide values for the above.

6.6. Service area and community characteristics

Community characterization is done by characterizing the above dynamics for each service area in the community that is by identifying the objectives, sought benefits, risks, mitigation plans, drawbacks, policies and strategies, success criteria for each service area. For this characterization, the size of the service area matters. The resources such as social and non-profit organizations and businesses in the area matter. Opportunities such as economic development opportunities in the service area matter. How the municipality sees the service area matters with respect to whether municipality considers significant investment or not in the area, and what social initiatives and public services are planned. Existence of substitutable offerings matters.

7. SD model estimating benefits, drawbacks and risks

Once the characterization phase is complete, the methodology suggests following the same intelligence framework for building models to estimate benefits, drawbacks and risks. In this paper, we develop a generic SD model taking into consideration the dynamics we characterized in earlier sections. The generic model in **Figure 4** shows how these dynamics influence each other. Then we will explain how the generic model could be instantiated for specific service areas.

The generic model shows the impact of success on users and the impact of user adoption to observed benefits. More users could lead to more benefits initially, but since some users will be blocked after the maximum allowed users, the quality and attractiveness of the wireless network will degrade. That will cause some users to quit, and will impact the observed benefits negatively. Positive loop from economic utility to observed benefits exists: when the quality and attractiveness of the wireless network is high, the economic utility for being on the platform will be high for users and other platform sides. When more users join, the observed benefits will increase to some extent. Negative loop also exists from low success to benefits: the low success on the objectives will degrade the quality and attractiveness of the wireless network, which will lead to lower economic utility for users and sponsors on the platform, which will reduce the amount of observed benefits. With small number of users, no big benefits could be achieved. If the critical mass is not reached, it may be partly due to non-effective policies and strategies.

Most benefits are intangible. In the simulation, some weights are assigned for benefit related attributes. Another advantage with SD analysis is to be able to simulate the uncertain benefits of the platform and compare the benefits under different scenarios through sensitivity analysis. Another challenge with measuring benefits is that some benefits are realized over a long term. Different statistical distributions may be used to take effect over time for the characterization of

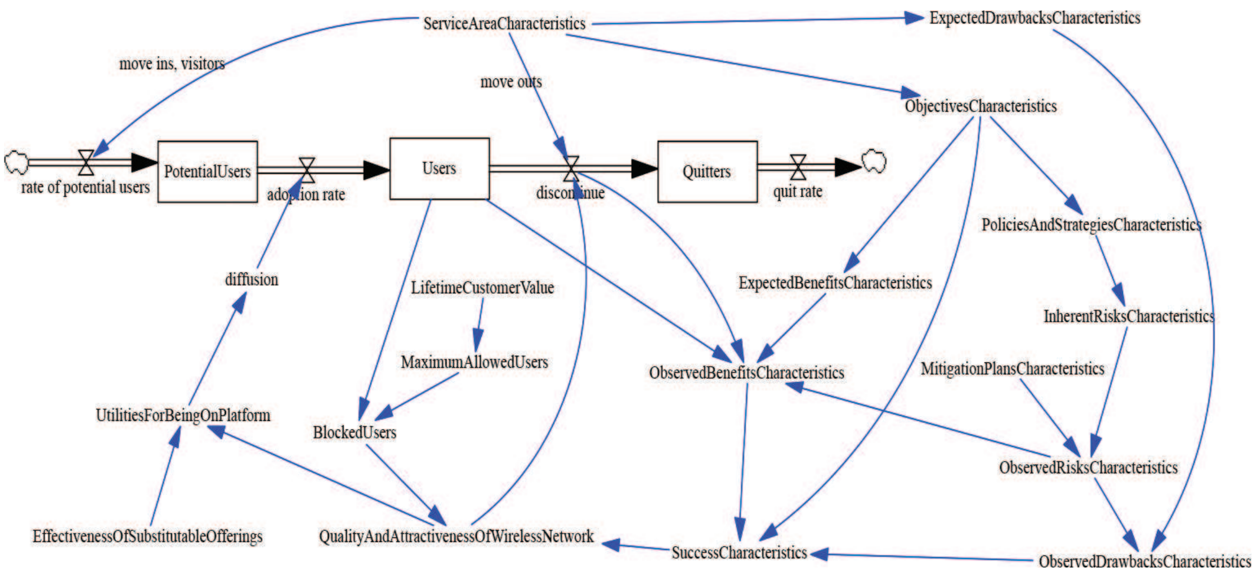

Figure 4. Generic model for measuring benefits of smart community wireless platform.

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community, service area and municipality, and that way, their impacts on the benefits are measured over a long term. Triggers for various dynamics at certain times help with analyzing the impacts over a long term.

The model contains all different characteristics and their relationships. Those characteristics include various variables corresponding to different aspects of characterization we outlined in earlier sections, although the variables are not visible in the diagram. When the model is instantiated for a specific service area, only the relevant variables are populated for each characteristics. Otherwise, a model that contains most variables is hard to build, nor would be helpful because of huge diversity in objectives, benefits, drawbacks, risks, policies and strategies. Rather the generic model is instantiated for each service area to simulate the different dynamics pertinent to the service area.

A typical instantiation of this generic model involves one-to-three objectives/benefits, one drawback, one risk and one mitigation plan in the model. Also, typically one smart service is incorporated into the model to simulate how it would impact the utility of the platform sides. More specifically, the smart service could be local to the service area and would not be available via the Internet in the instantiated model. This generic model allows analyzing the network effects of a single smart service. An example is how a new smart service by itself influences the network effects and the utilities in the service area. Another example is how community beacons or augmented reality introduced in a business district influence the network effects and utilities.

An instantiated model is used for estimating the benefits and drawbacks, and for analyzing the relations among benefits, drawbacks, risks and mitigation plans in existence of network externalities for a service area. When enough data is not available, SD modeling and simulation is still helpful by performing sensitivity analysis based on assumptions, heuristics, hypothesis, expert opinions, estimations and observations for providing insights to many managerial questions.

As the next steps in the methodology described earlier, the model is further verified and validated as more data becomes available. With more data about the dynamics being available while the wireless network is operational, models that use statistics and machine learning are built for clustering, classifying and predictions. Factor analysis is done on what dynamics affect the success of the platform the most. Statistical methods are used to see significant difference between different platforms and between different scenarios, and to test hypothesis about the relations among different dynamics related to the platform. Machine learning methods are built to analyze collected usage data per community network for predicting future use and demand forecasting, finding out covariance matrix, significant parameters, association rules regarding the success of the platforms. All these statistical, machine learning and economical models are integrated with the SD models and the SD model is validated and tuned using available data. With data, it is possible to do comparison between different service areas. We believe statistical, economic and machine learning methods alone are not sufficient to analyze complex platforms such as this one, and SD is most suitable to be used together with these methods, hence a more powerful intelligence framework for better analysis and understanding can be constructed [11].

The model should run over time for a service area to see how the benefits and drawbacks are realized over a period. The system should analyze all possible improvement strategies and tradeoffs, balancing required budgets and expected benefits.

8. Smart City wireless platform

When different smart community wireless platforms come together, is it possible to create a bigger platform for the whole city? We call this new platform the smart city wireless platform. In the bigger city-wide deployment of a smart city wireless platform, the municipality would be the sponsor of the platform to ensure order and control mechanisms. This platform requires additional infrastructure elements in the system architecture and has more sides compared to the smart community wireless platform. We explore it in [5].

9. Conclusion

A wireless network (e.g. a mesh Wi-Fi network) covering most of the city is a significant contributor toward being a smart city. Such a network offers many benefits but there are technical, economical and policy challenges for building and operating one. This paper presents a model where municipality, communities and smart utility providers work together to create a platform, the smart community wireless platform, where different sides work together toward achieving smart community objectives. The main advantage with this platform is that communities have clear objectives and needs, and have better predictions about the demand, and are small and manageable in sizes. The municipality does not allocate big budget for initial and ongoing cost. The network provides bandwidth for smart IoT devices and access to the services offered by smart service providers. This model allows collaboration among communities, municipality and smart service providers.

One question is how much would be the total cost of building and operating such a platform. To estimate the cost, relevant dynamics should be identified and characterized. An intelligence framework that incorporates SD modeling with statistical, economical and machine learning methods is very useful for estimating the total cost of smart community wireless platforms under various conditions and scenarios. In this paper, we developed models for estimating the initial and maintenance costs, and outlined how these models could be used to analyze different dynamics and scenarios. These models can be used by the community which is the platform sponsor and by the city which is a main supporter of the platform. Through simulations and sensitivity analysis, these models could provide insights about different cost components as well as about other dynamics of the platform.

Another question is how to measure the benefits and drawbacks of these platforms to estimate the returns on investment over a period. Another question is how to analyze the risks and mitigation plans for the success. To measure the benefits, relevant dynamics should be identified and characterized. The characterization phase should consider objectives, benefits, drawbacks, risks, policies, strategies and criteria of success for a specific service area in a community. The same intelligence framework that we used for estimating the total cost is applicable for estimating the benefits under various conditions and scenarios. In this paper, we developed a generic SD model for estimating the benefits and drawbacks, and for incorporating the causal loops among benefits, drawbacks, risks and mitigation plans in existence of network externalities. We outlined how the generic model could be instantiated for specific dynamics and to analyze different scenarios.

Another question is how the city could inspire and assist the communities to build their community wireless network, and then coalesce them for a city-wide wireless network. We address this question in [5].

Our future work includes running the models for different instantiations and comparing results. Our future work also includes combining the cost and benefit models together and running them to measure returns on investment for different scenarios.

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