Mesh Network Model for Urban Area

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ABSTRACT

MESH NETWORK MODEL FOR URBAN AREA

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Decreasing population, high crime rate, and limited economic opportunities are all symptoms of urban decline. These characteristics are, unfortunately, evident in major cities and small towns. Local municipalities in these cities and towns with the aid of state and federal government have attempted to reverse urban decline through the traditional approach of urban renewal. Their idea was to create low cost housing to attract people back to urban areas. Their approach has shown mixed results with most attempts having no effect on the deterioration. The goal of this thesis is to propose a higher system approach to answer urban decline through the application of new technology, wireless mesh networks. A wireless mesh network can provide improved security, public safety, new economic opportunities, and a bridge that crosses the digital divide. Married to the appropriate applications, a wireless mesh network creates a business model that is both favorable and sustainable. More importantly, the business model brings about the human capital necessary for urban revitalization.

Thesis Advisors:

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Chapter 1

INTRODUCTION

1.1 Background:

Urban decline is a common issue. The traditional approach to this problem has been funding and reinvestment in real estate. The goal of this chapter is to introduce a different approach to an age old issue – utilizing a mesh network as the backbone for urban revitalization. Key metrics will be defined to gage the success and failure of such an approach. This holistic method provides an improved business model for the implementation of a mesh network which, coupled with the appropriate applications, will justify municipal wireless mesh network deployment as well provides the means for urban revitalization.

1.2 The Problem of Urban Decline:

Urban decline is an issue that faces many cities in the United States and globally. The definition of urban decline has often been defined as a social problem associated with poorer living conditions, unemployment, and crime. Studies[1, 2, 3] in urban decline have gathered around several key metrics as indicators of urban decline:

Depopulation:

A major metric of urban decline is the number of residence within an urban area over a time period. Cities undergoing urban decay often have more people migrating away from the city than people coming in to live.

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1 Smith, Fred and Sarah Allen. "Urban Decline (and Success), US," EH.Net Encyclopedia, edited by Robert Whaples. February 10, 2008. URL http://eh.net/encyclopedia/article/Smith.Urban.Decline.doc.

2 Glaser, Edward L. and Matthew E. Kahn. "Sprawl and Urban Growth," Harvard Institute of Economic Research, Discussion Paper No. 2004.

3 Downs, Anthony. "Some Realities about Sprawl and Urban Decline," Housing Policy Debate, Volume 10, Issue 4, Fannie Mae Foundation, 1999.

High Crime Rates:

Increased in criminal activities is often a symptom of urban decay. Since these declining areas are often lacking in economic opportunities, some people would resort to illegal means to obtain money.

Low Income:

Typically in areas characterized with poorer living conditions are residences with lower income. Above average unemployment statistics are quite common within declining areas.

Examples of the US cities that are undergoing urban decline are Detroit, Michigan, [4] Cincinnati, Ohio, Glasgow in Scotland, and Canary Wharf in London. More locally, a small city A within the Northeastern part of the United States that is grasping with urban decline consists of the following sample statistics shown below. Table 1 indicates a steady decline in population over several years. The rest of the tables display the latest available information on crime, income, and employment. Multi-year statistics are available, but for demonstration purposes, the most recent information is sufficient. Note that besides a lower level of median income for City A, the education level of the general population of City A is below the state and national averages.

- Population Loss:

Population by Year		Change Rate
2000	35,080	N/A
2001	35,086	0.02%
2002	34,452	-1.81%
2003	33,884	-1.65%
2004	33,140	-2.20%
2005	32,518	-1.88%

Table 1: Population of a City A over 5 Years[5]

[4] http://en.wikipedia.org/wiki/Urban_renewal, May 2, 2008.

[5] "*City A* Profile." http://www.idcide.com/citydata/, May 3, 2008.

- Crimes:

Crime per 100,000 Persons	City A	State	USA
Violent Crime Total	1725.7	476.7	596
Murder/NMH	2.9	3.1	7.1
Forcible Rape	79.4	29.5	37.2
Robbery Rate	546.8	133.1	201.7
Aggravated Assault	1096.5	321.4	350
Property Crime Total	3786.5	2622.3	4295.6
Burglary	1008.3	566.4	839.0
Larceny Theft	1772.7	1664.5	2887.2
Motor Vehicle Theft	1005.4	391.3	571.7
Arson	35.3	8.9	28.1

Table 2: Crime Statistics[6]

- Income:

Income Characteristics	City A ($)	Massachusetts ($)
Median Household Income	34,087	57,698
Average Household Income	44,290	75,023
Per Capita Income	15,470	29,196
Median Disposable Income	30,147	48,105

Table 3: Income Characteristics

[6] "Crime Report for *City A*, Massachusetts." http://www.homesurfer.com/crimereports/view/Crime_Report.cfm?state=OH&area=Cincinnati, May 2, 2008. Data comes from the FBI Uniform Crime Rate database for 2004.

Median Income by Age	City A ($)	Massachusetts ($)
Age < 25	36,786	34,952
Age 25-34	36,557	55,670
Age 35-44	38,662	65,765
Age 45-54	41,005	71,271
Age 55-64	32,039	63,841
Age 75-74	23,038	44,491
Age 75+	19,625	32,524

Table 4: Income Characteristics by Age[7]

- Education:

Educational Attainment	City A	City A	MA (2000)	US (2000)
Total (Population 25 years and older)	21,597	100%	4,273,275	182,211,639
Less than 9th grade	4,758	22%	5.8%	7.5%
9th to 12th grade, no diploma	3,995	18.5%	9.4%	12.1%
High School Graduate (includes equivalency)	6,497	30.1%	27.3%	28.6%
Some College, no degree	3,064	14.2%	17.1%	21.0%
Associate degree	1,119	5.2%	7.2%	6.3%
Bachelor's degree	1,513	7.0%	19.5%	15.5%
Graduate or professional degree	651	3.0%	13.7%	8.9%
high school graduate or higher	-	59.5%	84.8%	80.4%
bachelor's degree or higher	-	10.0%	33.2%	24.4%

Table 5: Education of Population[8]

[7] "*City A*, MA Homes For Sale and Real Estate Data." http://www.realestate.com/ , May 3, 2008.

- Unemployment and Poverty Level:

Statistic (Year)	City A	MA	USA
Unemployment (2000)	7.9%	4.6%	5.8%
Individual Poverty Level (2000)	23.3%	9.3%	12.4%
Family Poverty Level (2000)	20.6%	6.7%	9.3%

Table 6: Unemployment and Poverty Statistics[8]

Neglected, most urban decaying areas will continue to decline. Such cities will start to impact neighboring cities and towns. Most notably, individual criminal activities may transform into gang activities. Migration will further increase to farther distances and eventually to another state. Reversing the situation becomes more difficult as the higher skilled people move out of the city.

1.3 Causes of Urban Decline:

Urban decline can not be attributed to one factor. The causes of urban decline are not clear. However, there have been many theories and most of the theories revolve around depopulation.

During the industrial revolution, cities grew by attracting workers. The United States was transforming into a manufacturing, industrial society.[9] The factories within cities provided jobs for laborers.

With the advent of the automobile, the landscape changed. Workers need not live near their workplace. Factories can be further away from the city where the land is cheaper. This mobility brought upon population migration away from the

[8] U.S. Census Bureau, 2000, http://factfinder.census.gov, May 3, 2008.

[9] Kelly, Martin. "Overview of the Industrial Revolution – Industrial Revolution," http://americanhistory.about.com/od/industrialrev/a/indrevoverview.htm, May 3, 2008.

city. According to Edward Glaeser and Joseph Gyourko, their paper modeled a declining city caused by the reduction in housing demand. Migration away from the city increases the availability of housing and lowers housing prices. The reduction in housing prices attracts the poorer and less-educated populace, people with less human capital. A city with less-skilled workers has a more difficult time in reversing urban decline as was the case in Detroit[10].

In the 21st century, with the advancement in information technology and communications, American workers can now work at home. Technology along with the automobile (including highways) has encouraged the new generation of workers to continue migrating away from the city. Workers can either video or audio conference from home. With this type of scenario, the urban decline will continue with workers moving to the suburbs, attracted by the lower crime rate and larger living spaces.

1.4 Present Approaches:

The present solution to urban decline within the United States has been urban renewal or land redevelopment. Urban renewal in its simplest form meant demolishing old houses and rebuilding new houses for low income families. The outcomes of such programs, which have been applied to mostly large cities, have often been mixed results as the following random examples show.

1.4.1 Cincinnati:

Local residents invested about $1 billion in the development of two professional stadiums, a baseball and football stadiums.[11] Other public funded projects include a convention center and about $4 billion worth

[10] Glaesar, Edward L., and Joseph Gyourko. "Urban Decline and Durable Housing," Institute for Urban Research, Penn IUR Publications, 2005.

[11] Staley, Sam. "Ground Zero in Urban Decline," reasononline, http://www.reason.com/news/show/28209.html, Nov. 2001.

of reinvestment into the downtown district. So far, the population of Cincinnati has been still been decreasing 1.5% annually, and parts of the city are plagued by crime as the 2006 statistics show. More shockingly is the increase in unemployment and the number of individuals falling below the poverty line.

However, more positively, a section of the city called the Digital Rhine did manage to prosper. The sector consists of neighborhood of high tech and entreprenurial companies. The nonprofit organization Main Street Ventures[12] has promoted network forums for seeding and supporting the development of new ideas in technology within the area. The goal is to attract highly technical people and investment capital to this section of the city. So far, the program has been successful with at least 20 Internet start-ups including companies like eToy and Citysearch.[13]

- Population Loss:

Population by Year		Change Rate
2000	331,285	N/A
2001	327,342	-1.19%
2002	322,234	-1.56%
2003	318,146	-1.27%
2004	313,860	-1.35%
2005	308,728	-1.64%

Table 7: Population of Cincinnati over 5 Years[14]

[12] "Main Street Ventures," http://www.irhinc.com, May 12, 2008.

[13] Byczkowski, John. "Over-the-Rhine becoming Silicon Alley," Cincinnati Enquirer, http://www.enquirer.com/editions/1999/10/24/fin_over-the-rhine.html, May 12, 2008.

[14] "Cincinnati, Ohio Profile," http://www.idcide.com/citydata/oh/cincinnati.htm, May 2, 2008.

- Crimes:

Crime	Cincinnati	OH	Nation
Violent Crime Total	1148.1	557.0	596
Murder / NNH	20.1	7.0	7.1
Forcible Rape	97.5	57.0	37.2
Robbery Rate	756.3	268.0	201.7
Aggravated Assault	274.2	224.0	350
Property Crime Total	7145.5	4967.0	4295.6
Burglary	1753.1	1176.0	839.0
Larceny Theft	4493.0	3226.0	2887.2
Motor Vehicle Theft	899.4	564.0	571.7
Arson	78.3	50.0	28.1

Table 8: Cincinnati Crime Statistics per 100,000 Persons[15]

- Income:

Income Characteristics	Cincinnati ($)	Ohio($)
Median Household Income	33,024	46,618
Average Household Income	48,263	59,031
Per Capita Income	23,246	24,061
Median Disposable Income	29,319	40,002

Table 9: Income Characteristics for Cincinnati[16]

[15] "Crime Report for Cincinnati, Ohio," http://www.homesurfer.com/crimereports/view/Crime_Report.cfm?state=OH&area=Cincinnati, May 2, 2008. Data comes from the FBI Uniform Crime Rate database for 2004.

[16] "Cincinnati, OH Homes For Sale and Real Estate Data," http://www.realestate.com/OH/Cincinnati/Cincinnati-Area-Info-Income.aspx, May 3, 2008

Median Income by Age	Cincinnati ($)	Ohio ($)
Age < 25	24,199	28,822
Age 25-34	34,361	45,189
Age 35-44	37,273	53,981
Age 45-54	39,738	59,582
Age 55-64	34,758	51,678
Age 75-74	29,934	37,102
Age 75+	27,455	29,737

Table 10: Income Characteristics by Age for Cincinnati[16]

- Education:

Educational Attainment	Cincinnati	Cincinnati	Ohio	USA
Total (Population 25 years and older)	207,254	192,898	7,602,462	195,932,824
Less than 9th grade	5.8%	4.8%	3.6%	6.5%
9th to 12th grade, no diploma	17.5%	14.2%	10.2%	9.4%
High School Graduate (includes equivalency)	25.8%	28.8%	37.1%	30.1%
Some College, no degree	18.9%	16.9%	19.1%	19.5%
Associate degree	5.4%	7.2%	7.1%	7.4%
Bachelor's degree	16.4%	16.8%	14.7%	17.1%
Graduate or professional degree	10.3%	11.3%	8.3%	9.9%
High school graduate or higher	76.7%	81.0%	86.2%	84.1%
bachelor's degree or higher	26.6%	28.1%	23.0%	27.0%

Table 11: Education of Population in Cincinnati[17,18]

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[17] U.S. Census Bureau, Cincinnati, Ohio, 2000, http://factfinder.census.gov, May 3, 2008.

- Unemployment and Poverty:

Statistic	Cincinnati 2000	Cincinnati 2006	Ohio 2006	USA 2006
Unemployment	7.3%	10.2%	7.1%	6.4%
IndividualPoverty Level	21.9%	27.8%	13.3%	13.3%
Family Poverty Level	18.2%	23.4%	9.8%	9.8%

Table 12: Unemployment and Poverty Statistics in Cincinnati[17,18]

1.4.2 Detroit:

The plan in 2004 was to redevelop 1200 acres of land, build three casinos and create an entertainment mecca around new sports stadiums.[19] General Motors is taking the lead in working with different organizations in revitalizing the downtown arena starting with the Renaissance Center. Even with all this urban renewal planning, the population continues to decrease, and crime remains high. Representative of the lack of economic opportunity is the drastic jump in unemployment figures from 2000 to 2006 (See Table 18).

[18] U.S. Census Bureau, Cincinnati, Ohio, 2006, http://factfinder.census.gov, May 3, 2008.

[19] Peirce, Neal. "Massive urban renewal: Detroit's 21st-Century formula," http://www.stateline.org, The Washington Post Writers Group, 2004..

- Population Loss:

Population by Year		Change Rate
2000	951,270	N/A
2001	934,694	-1.74%
2002	922,426	-1.31%
2003	911,851	-1.15%
2004	899,122	-1.40%
2005	886,671	-1.38%

Table 13: Population of Detroit over 5 Years[20]

- Crimes:

Crime	Detroit	MI	Nation
Violent Crime Total	1740.4	723.3	596
Murder / NNH	42.1	10.4	7.1
Forcible Rape	78.6	55.1	37.2
Robbery Rate	596.2	189.3	201.7
Aggravated Assault	1023.5	468.4	350
Property Crime Total	6279.3	3790.0	4295.6
Burglary	1334.5	773.6	839.0
Larceny Theft	2257.3	2300.3	2887.2
Motor Vehicle Theft	2687.5	770.8	571.7
Arson	189.6	52.4	28.1

Table 14: Detroit Crime Statistics per 100,000 Persons[21]

[20] "Detroit, Michigan Profile." http://www.idcide.com/citydata/mi/detroit.htm, May 2, 2008.

[21] "Crime Report for Detroit, Michigan," http://www.homesurfer.com/crimereports/view/crime_report.cfm?state=MI&area=Detroit, May 3, 2008. Data comes from the FBI Uniform Crime Rate database for 2004.

- Income:

Income Characteristics	Detroit ($)	Michigan($)
Median Household Income	33,028	50,882
Average Household Income	45,691	65,042
Per Capita Income	17,116	26,161
Median Disposable Income	29,310	42,986

Table 15: Income Characteristics for Detroit[22]

Median Income by Age	Detroit ($)	Michigan ($)
Age < 25	24,311	31,520
Age 25-34	31,063	48,138
Age 35-44	35,244	58,068
Age 45-54	39,711	65,407
Age 55-64	36,526	56,729
Age 75-74	29,216	39.093
Age 75+	25,321	30,636

Table 16: Income Statistics for Detroit[22]

[22] "Detroit, MI Homes for Sale and Real Estate Data," http://www.realestate.com/MI/Detroit/Detroit-Area-Info-Income.aspx, May 3, 2008.

- Education:

Educational Attainment	Detroit	Detroit	Michigan	USA
Total (Population 25 years and older)	563,979	506,895	6,636,666	195,932,824
Less than 9th grade	7.8%	6.8%	3.8%	6.5%
9th to 12th grade, no diploma	22.5%	17.5%	9.0%	9.4%
High School Graduate (includes equivalency)	30.0%	35.7%	32.5%	30.1%
Some College, no degree	23.5%	22.6%	22.5%	19.5%
Associate degree	5.1%	6.1%	7.8%	7.4%
Bachelor's degree	6.8%	7.3%	15.3%	17.1%
Graduate or professional degree	4.2%	3.9%	9.1%	9.9%
High school graduate or higher	69.6%	75.7%	87.2%	84.1%
Bachelor's degree or higher	11.0%	11.3%	24.5%	27.0%

Table 17: Education of Population in Detroit[23, 24]

- Unemployment and Poverty:

Statistic	Detroit 2000	Detroit 2006	Michigan 2006	USA 2006
Unemployment	13.8%	22.2%	9.5%	6.4%
Individual Poverty Level	26.1%	32.5%	13.5%	13.3%
Family Poverty Level	21.7%	27.0%	9.6%	9.8%

Table 18: Unemployment and Poverty Statistics in Detroit[23,24]

[23] U.S. Census Bureau, Detroit, Michigan, 2000, http://factfinder.census.gov, May 3, 2008.

[24] U.S. Census Bureau, Detroit, Michigan, 2006, http://factfinder.census.gov, May 3, 2008.

1.4.3 Boston:

Urban renewal for Boston was done in much a similar manner as Detroit and Cincinnati. Sections of the city were redeveloped at different times.[25] Urban housing was emphasized early in the 1950's. Later on, the emphasis was on the business districts, such as downtown and Faneuil Hall. Although the populations is still declining, and the crime rate is higher than the state, other statistics for Boston show a much more positive trend. The unemployment rate has decreased from 2000 to 2006. The amount of highly skill people have increased in Boston. In fact, statistics indicate that the percentage of people with Bachelor's degree or higher in Boston is more than doubled Detroit's percentage, and far exceeds Cincinnati's. People with these skill levels are necessary in reversing urban decline.

Boston's high level of skilled workers can be attributed to the schools, colleges, and universities within the area. These centers of education are also responsible for luring the high-tech and biotechnology industries to the region. Thus Boston was able to reinvent itself as a high-technology area.[26] And in a manner similar to the Digital Rhine sector in Cincinnati, Boston was able to prosper by utilizing its technology industries to attract higher human capital. Moreover, Boston is capable of generating its own higher human capital through its education system.

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[25] Grauds, Juris A. "Urban Renewal in New Haven and Boston, Transgression and Triumph?" Current Issues in Cities and Suburbs, November 2005.

[26] Glaesar, Edward L. "Reinventing Boston: 1640-2003," NBER Working Paper Series, Working Paper 10166, http://www.nber.org/papers/w10166, December 2003.

- Population Loss:

Population by Year		Change Rate
2000	589,141	N/A
2001	590,293	0.20%
2002	585,259	-0.85%
2003	577,432	-1.34%
2004	567,660	-1.69%
2005	559,034	-1.52%

Table 19: Population of Boston over 5 Years[27]

- Crimes:

Crime	Boston	MA	Nation
Violent Crime Total	1192.4	476.7	596
Murder / NNH	10.5	3.1	7.1
Forcible Rape	46.4	29.5	37.2
Robbery Rate	418.6	133.1	201.7
Aggravated Assault	717.0	321.4	350
Property Crime Total	4760.7	2622.3	4295.6
Burglary	783.5	566.4	839.0
Larceny Theft	3021.3	1664.5	2887.2
Motor Vehicle Theft	955.9	391.3	571.7
Arson	0.0	8.9	28.1

Table 20: Boston Crime Statistics per 100,000 Persons[28]

[27] "Boston, MA Profile," http://www.idcide.com/citydata/ma/boston.htm, May 2, 2008.

[28] "Crime Report for Boston, Massachusetts," http://www.homesurfer.com/crimereports/view/Crime_Report.cfm?state=MA&area=Boston, May 2, 2008.

- Income:

Income Characteristics	Boston ($)	Massachusetts($)
Median Household Income	44,050	57,698
Average Household Income	62,161	75,023
Per Capita Income	26,556	29,196
Median Disposable Income	38,154	48,105

Table 21: Income Characteristics for Boston[29]

Median Income by Age	Boston ($)	Massachusetts ($)
Age < 25	30,201	34,952
Age 25-34	50,169	55,670
Age 35-44	48,360	65,765
Age 45-54	50,589	71,271
Age 55-64	43,879	63,841
Age 75-74	32,655	44,491
Age 75+	26,787	32,524

Table 22: Income Statistics for Boston[29]

[29] "Boston, MA Homes For Sale and Real Estate Data," http://www.realestate.com/MA/Boston/Boston-Area-Info-Income.aspx, May 5, 2008.

- Education:

Educational Attainment	Boston	Boston	Massachusetts	USA
Total (Population 25 years and older)	377,574	381,558	4,345,561	195,932,824
Less than 9th grade	9.1%	8.2%	5.0%	6.5%
9th to 12th grade, no diploma	12%	8.0%	7.1%	9.4%
High School Graduate (includes equivalency)	24%	25.3%	28.2%	30.1%
Some College, no degree	14.5%	11.9%	15.0%	19.5%
Associate degree	4.9%	5.0%	7.7%	7.4%
Bachelor's degree	20.2%	23.1%	21.4%	17.1%
Graduate or professional degree	15.3%	18.4%	15.6%	9.9%
High school graduate or higher	78.9%	83.7.%	87.9%	84.1%
bachelor's degree or higher	35.6%	41.6%	37.0%	27.0%

Table 23: Education Level in Boston[30,31]

- Unemployment and Poverty:

Statistic	Boston	Boston	Massachusetts	USA
Unemployment	7.2%	6.4%	5.8%	6.4%
Individual Poverty Level	19.5%	19.8%	9.9%	13.3%
Family Poverty Level	15.3%	15.6%	7.0%	9.8%

Table 24: Unemployment and Poverty in Boston[30,31]

[30] U.S. Census Bureau, Boston, MA, 2000, http://factfinder.census.gov, May 5, 2008.

[31] U.S. Census Bureau, Boston, MA, 2006, http://factfinder.census.gov, May 5, 2008.

1.5 Mesh Network Approach:

The highways have often been compared as the lifelines to the cities. The cities depend on the expressways for all forms of economic and social activities. In a similar manner, a wireless mesh network can be the backbone to urban revitalization as the rest of this thesis will demonstrate. A mesh network infrastructure providing connectivity over an urban area will influence security, population, education, and income levels directly and indirectly.

There are other competing technologies to wireless mesh networks, but none measures in cost and performance. The most ubiquitous communication technology capable of high speed data transfer rates is 3G networks. Table 25 shows the cost of installing 3G equipment and Tropos wireless mesh nodes over 34 square miles in Manhattan. The high cost of 3G includes installing 64 cell towers. On the other hand, mesh network nodes can be installed on lamp posts and top of buildings. In addition, the performance of 3G is much lower than that of wireless mesh network. High bandwidth is a requirement for video applications, which are necessary to reduce crime. Lower crime rate areas can attract higher human capital and more economic opportunities.

	Cells	Cost	Performance
3G (1x EV-DO)	64	~$8M	⇩ 150-400 kbps ⇧ 10-50 kbps
Wi-Fi TROPOS networks	600	<$2M	500-2,000 kbps *symmetric*

Table 25: Cost Comparison of Wireless Mesh Network with 3G[32]

- ♠ -

[32] Tropos Networks. "Price-Performance Comparison: 3G and Tropos MetroMesh Architecture," A Technology Whitepaper, July 2007.

Chapter 2

WIRELESS MESH NETWORK THEORY AND PRACTICE

2.1 Wireless Mesh Network Overview:

Wireless mesh networking is a unique way of applying radio and Wi-Fi technologies. A wireless mesh network is similar to a wireless LAN employing mesh topology. The difference is that each node or access point serves as a router and a wireless provider and can communicate with its neighboring nodes. For example Figure 1 displays a mesh network. There is no centralized management and the architecture follows a mesh topology. Communication is performed by transmitting packets via radio waves from node to node until the packets reach their destination.

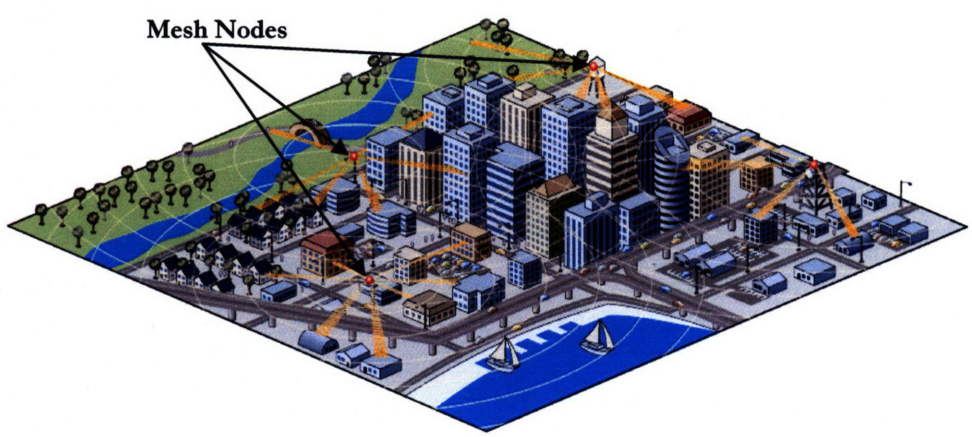

Figure 1: An Urban Wireless Mesh Network[33]

With certain mesh networking technology, the client within the mesh network can also be a transmitting and receiving node (i.e. the laptop can itself be a node).

[33] Wavion, Inc.,"WS410 Spatially Adaptive Wi-Fi Access Point," 2007, p.3.

This type of technology is more applicable for MacroMesh networks. MacroMesh network, mostly used in millitary applications, are large dynamic networks that emphasizes mobility and scability. The application of the wireless mesh technology that this thesis is investigating is within declining neighborhoods. Therefore, the assumption that the client can afford additional hardware is unrealistic.

2.2 Capacity and Performance of Mesh Network Generations:

There have been three generations of mesh networks. The line of differentiation between generations has been the number of radios used. Each generation is a step up in capacity.

2.2.1 First Generation Mesh Network:

First generation mesh networks used one Wi-Fi radio. Figure 1 illustrates a first generation network, a chain of N nodes. Studies have indicated that the asymptotic capacity of such a network is O(1/N).[34] Aside from generating packets, each node must be able to forward packets, like a repeater. Therefore, in order to reach the backhaul, all the nodes must forward their packets to node 1. Since this example uses only a single radio frequency, each node must share the capacity when accessing one another or interacting with the client. Single radios employ one channel. The backhaul may be a wired network (fiber or cable) or, if wireless, WiMAX.

The performance of the network is also measured in worse case latency. In regards to first generation mesh networks, the Nth node will take N hops to reach the backhaul. Thus, the more access points to the backhaul there are, the higher the performance and capacity of the mesh network

[34] Jun, Jangeun, and Mihail L. Sichitiu. "The Nominal Capacity of Wireless Mesh Networks," North Carolina State University, pp. 1-6.

will be. The limitation then would be the capacity of the backhaul. Figure 2 represents an N chain network with single radio.

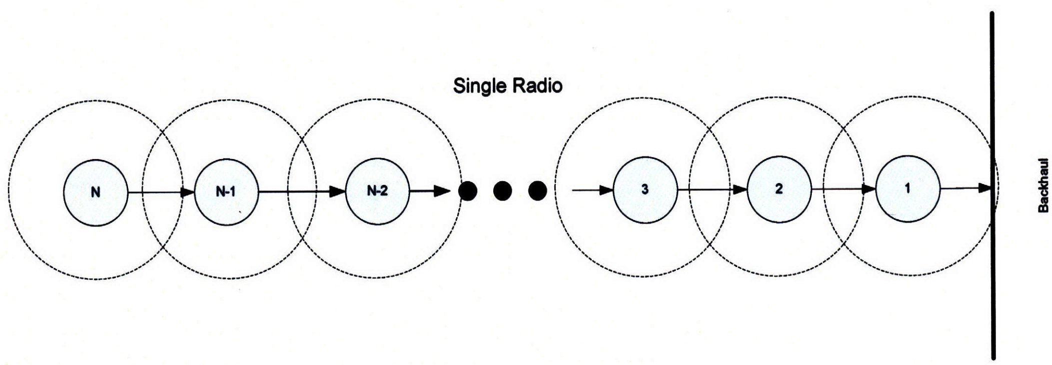

Figure 2: N Chain Network[35]

2.2.2 *Second Generation Mesh Network:*

The second generation mesh network consists of two radios for communications. One radio is dedicated to backhaul, and the other for client services. Normally, the backhaul radio is an 802.11a radio, and the other one is an 802.11b/g radio. 802.11b/g radios have multiple channels to avoid interference. Adjacent nodes are servicing clients with different channels. However, the backhaul capacity is still shared, although client services for each nod is autonomous. Node 1 must be able to handle up to N packets to the backhaul. Therefore, similarly to first generation mesh networks, the capacity for second generation mesh networks is asymptotically O(1/N).

Figure 3 is an example of a dual radio mesh network. Adjacent client services are performed over channel A or B to avoid interference. The outer circle represents the 802.11a radio that links back to the backhaul.

[35] "Capacity of Wireless Mesh Networks." BelAir Networks, Whitepaper, 2006, pp. 1-16.

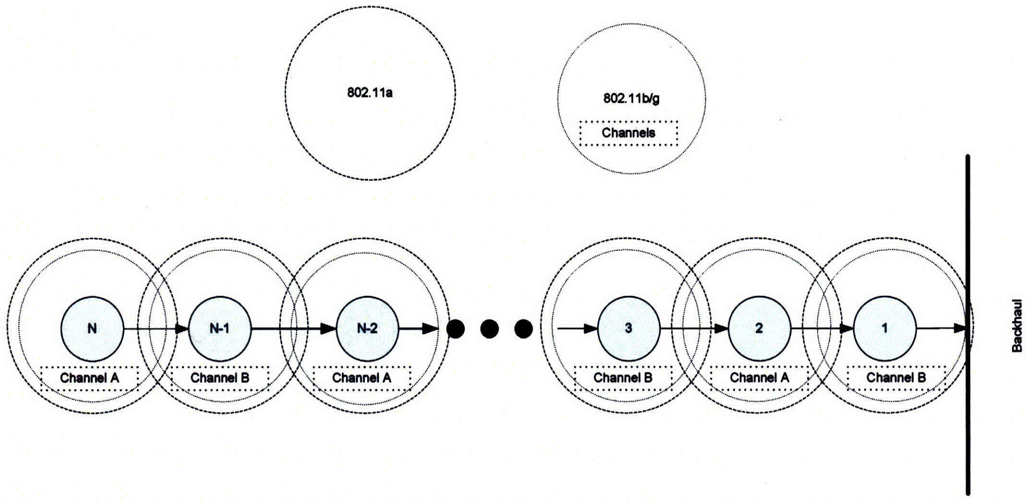

Figure 3: Dual Radio Wireless Mesh Network[35]

2.2.3 *Third Generation Mesh Network:*

Third generation mesh networks makes use of multiple radios with multiple channel capabilities as radio technology becomes more affordable. The architecture for third generation mesh networks has multiple access points to the backhaul. The system designer can specify the maximum number of hops to the backhaul as long as backhaul access is available through wired or wireless services. The behavior of third generation mesh networks is much similar to switched circuit networks.

Figure 4 represents a 3rd generation wireless mesh network. Client services are performed over either channel A or B for each node without interfering with neighboring nodes. The backhaul radio is also capable of multiple channels. Note that there are now multiple paths to the backhaul. Each node can operate independently from the others.

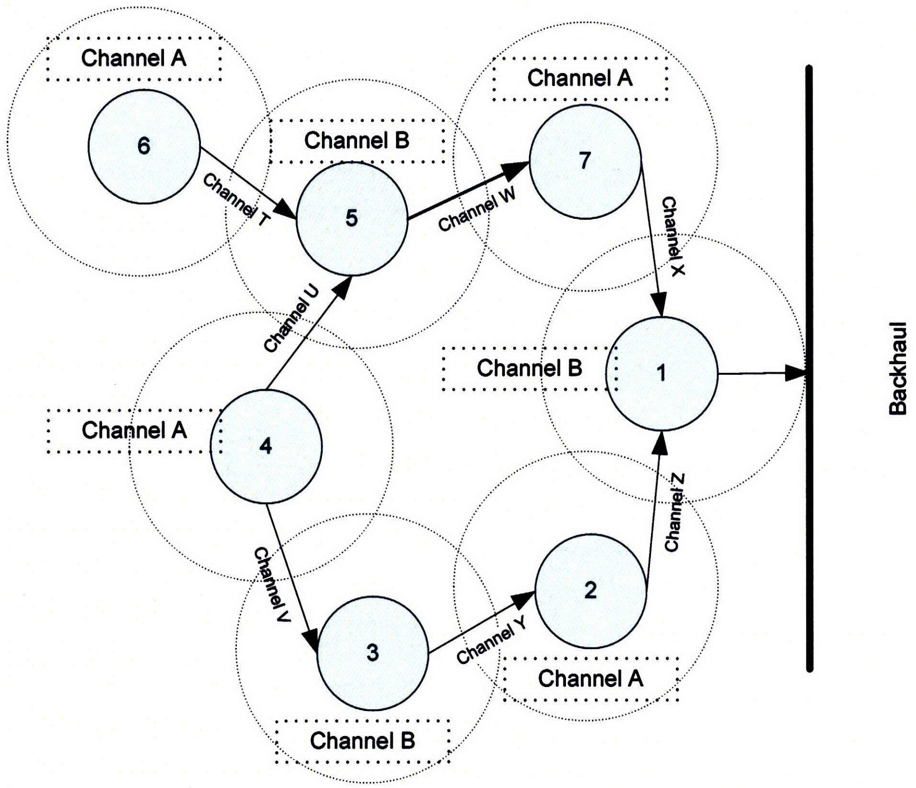

Figure 4: Third Generation Wireless Mesh Network[35]

2.2.4 Performance Comparisons:

The performance of the three generations of mesh networks are shown in Figure 5. The graph demonstrates that as the number of nodes or access points (AP) increases, each AP access capacity decreases, especially with single and dual radio topology. On the other hand, APs in multi-radio mesh network topology eventually decreases in node capacity as the number of nodes increases beyond six APs. For the multi-radio mesh network, the configuration is assumed to be a string of six access points with one channel dedicated to the back haul. The bottleneck for the multi-radio mesh network is the wired backhaul.

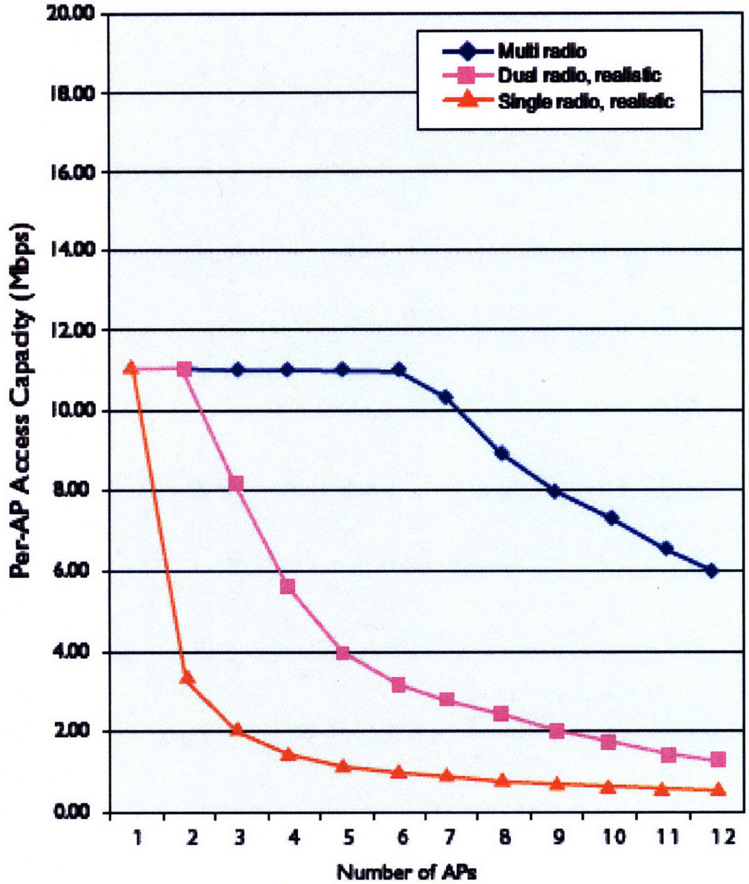

Figure 5: Radio Mesh per Capacity[35]

2.3 Radio Technologies – the Wi-Fi Standards – IEEE 802.11:

Mesh network technologies uses radios supporting the Wi-Fi standards created by IEEE; these standards are known as 802.11. The terms Wi-Fi and 802.11 typically refer to the same standard; however, only recently, the Wi-Fi alliance has been altering the definition of Wi-Fi to include a different set of overlapping standards.[36] Table 26 shows the different variations of the 802.11 standard.

[36] "IEEE 802.11," http://en.wikipedia.org/wiki/802.11, April 20, 2008.

Protocol	Release Date	Op. Frequency	Throughput (Typ)	Data Rate (Max)	Modulation Technique	Range (Radius Indoor) Depends, # and type of walls	Range (Radius Outdoor) Loss includes one wall
Legacy	1997	2.4 GHz	0.9 Mbit/s	2 Mbit/s		~20 Meters	~100 Meters
802.11a	1999	5 GHz	23 Mbit/s	54 Mbit/s	OFDM	~35 Meters	~120 Meters
802.11b	1999	2.4 GHz	4.3 Mbit/s	11 Mbit/s	DSSS	~38 Meters	~140 Meters
802.11g	2003	2.4 GHz	19 Mbit/s	54 Mbit/s	OFDM	~38 Meters	~140 Meters
802.11n	June 2009[3] (est.)	2.4 GHz 5 GHz	74 Mbit/s	248 Mbit/s		~70 Meters	~250 Meters
802.11y	June 2008[3] (est.)	3.7 GHz	23 Mbit/s	54 Mbit/s		~50 Meters	~5000 Meters

[3] Official IEEE 802.11 working group project timelines (2007-11-15). Retrieved on 2007-11-18.

Table 26: Summary of 802.11 Standards[36]

Presently, the 802.11b/g is the ubiquitous standard. One of the advantages of 802.11 b/g is the availability of multiple channels to minimize interference within the 2.4GHz frequency. The overlapping and non-overlapping channels are shown in Figure 6.

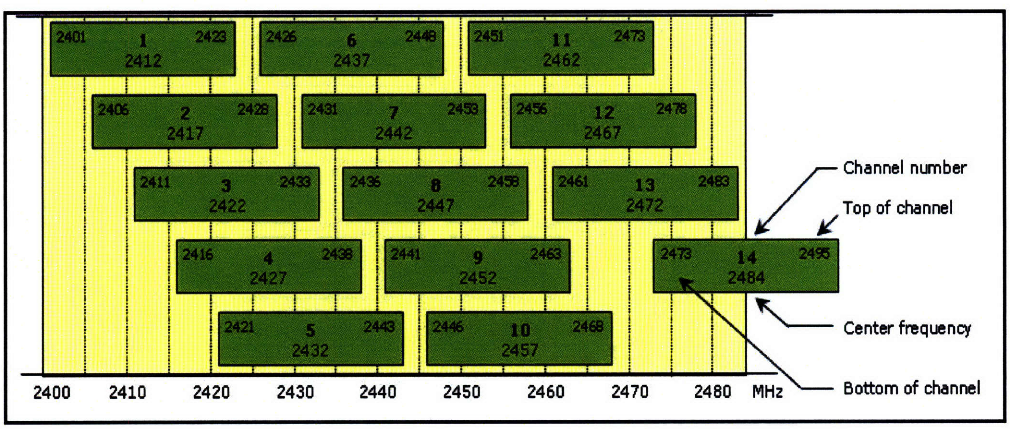

Figure 6: 802.11b/g Frequency Bands[37]

[37] "802.11b WiFi Channels," http://www.moonblinkwifi.com/2point4freq.cfm, May 6, 2008.

The IEEE is also working on the new standard 802.11n. 802.11n promises higher bandwidth and better coverage. The frequency bands of 802.11n are shown in Figure 7.

Frequency Band (GHz)	Independent 20 MHz Channels	Possible 40 MHz Channels	
2.40–2.485	3	1	Indoor/outdoor
5.15–5.25	4	2	Indoor only
5.25–5.35	4	2	Indoor/outdoor
5.47–5.75	10	5	Indoor/outdoor, dynamic frequency selection and power control
5.75–5.85	4	2	Outdoor
Total	25	12	

Figure 7: 802.11n Frequency Bands[38]

Radio performance in mesh network deployments is also the most difficult to predict. Radio coverage around a node is normally estimated to be a circular area around a node. In practice, this estimate is not realistic. Radio propagation is dependent on the type of antenna, the density of the users (people themselves are obstacles), and the environment (RF interference, topology, buildings, trees, etc.). For an omnidirectional antenna, the vertical coverage is far from circular when compared to the horizontal coverage (See Figure 8). Figure 9 displays an example of the signal strength for a Wi-Fi transmitter within an urban setting[39]. Adjacent

38 Belanger, Phil and Ken Biba. "802.11 Unlocks the Potential of the 5GHz band," enterprise networking planet, http://www.enterprisenetworkingplanet.com/netsp/article.php/3695106, November 2007.

39 Sridhara, Vinay, and Stephan Bohacek. "Realistic Propagation Simulation iof Urban Mesh Networks," University of Delaware, p. 5.

nodes would have to be placed vertically or horizontally away in order to communicate with this node.

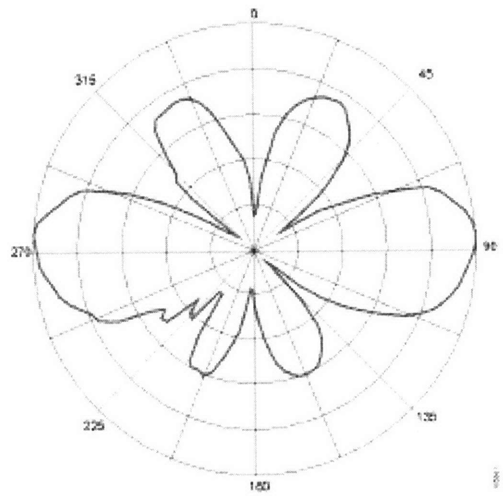

Figure 8: Vertical Coverage of Omnidirectional Antenna[40]

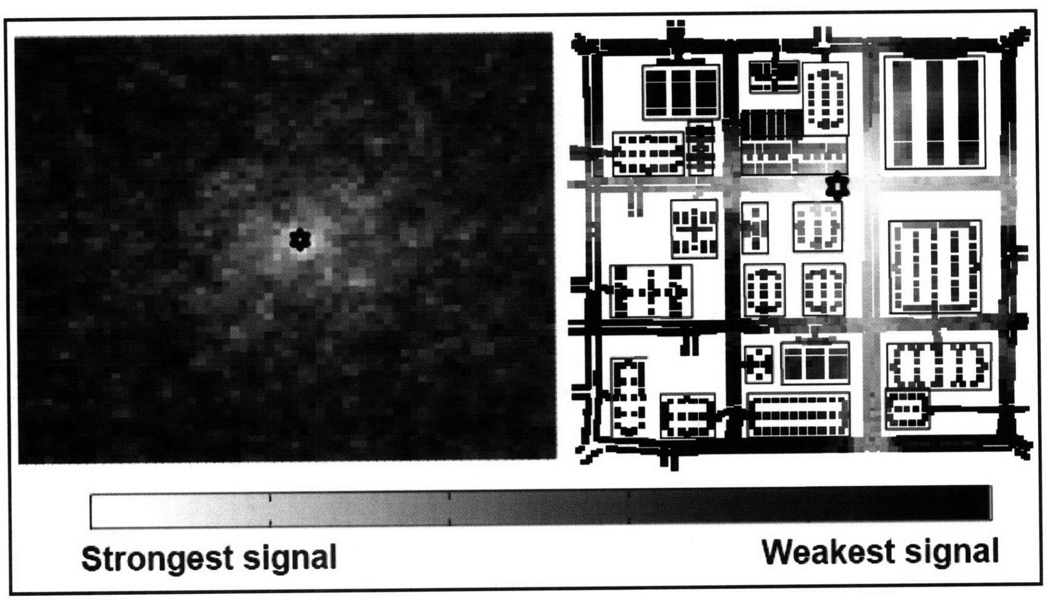

Figure 9: Strength of Signal within an Urban Setting39

[40] InPath. "High performance parabolic dish wireless lan antenna for ieee 802.11a wireless gear," 2005.

2.4 Advantages of Mesh Networks:

Wireless mesh networks have many advantages over other communication networks. Some of these advantages include:

- Wireless connection; very few wire connections, therefore the cost of implementing a mesh network is lower.

- Scalable: Increasing the number of nodes increases the speed of the network. Installation is also very simple using an omni antenna. A node can configure itself when added on.

- Wireless mesh networks employ a proven common technology, Wi-Fi standards (802.11a, b and g).

- Near Line of Sight (NLoS) coverage: Increasing the density of nodes increases the coverage area and eliminates "dead" spots.

- Reliability: Mesh networks have routing redundancy. If a node goes down, packets will automatically be routed around that particular node.

- No centralized management – packets do not have to return to a central server.

2.5 Disadvantages of Mesh Networks:

Conversely, wireless mesh networks have disadvantages:

- Unpredictable coverage area: As a result of the unpredictable behavior of radio waves within urban settings, more nodes may be needed than expected. To obtain the expected coverage may require the installation of a lot more nodes than expected.

- Lower than expected channel capacity: Presently, mesh network deployers have difficulty in predicting the overall bandwidth of the mesh networks. There are plans for up to N Mbps, but realistically, deployers have only been able to obtain best effort of < N Mbps.

- Require sophisticated software for bandwidth management: Each node serves as a router and client service provider. The software must be able to help route the forwarding packets from one node to the backhaul or to another destination node with minimal hops as well as serve local client demands. Latency is a potential issue in mesh networks.

- Progressive Deployment: Each node must be progressively added on from the backhaul to ensure communications between nodes.

- Security: Security has always been an issue where the Internet is involved. In the case of mesh networks, intermediate nodes can capture data destined for other nodes. Typically, on the Internet, end-to-end VPN techniques have been used to secure data transfers.

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Chapter 3

MUNICIPALITY WI-FI BEST PRACTICE/LESSONS LEARNED

3.1 Municipal Wi-Fi Business Models and Issues:

Presently, there are more than three hundred Wi-Fi initiatives underway at municipalities. Some have been successfully deployed, while others have temporarily or permanently halted at different stages. The typical municipal Wi-Fi business models are displayed in Figure 10. The most common issues discovered in mesh deployment were:

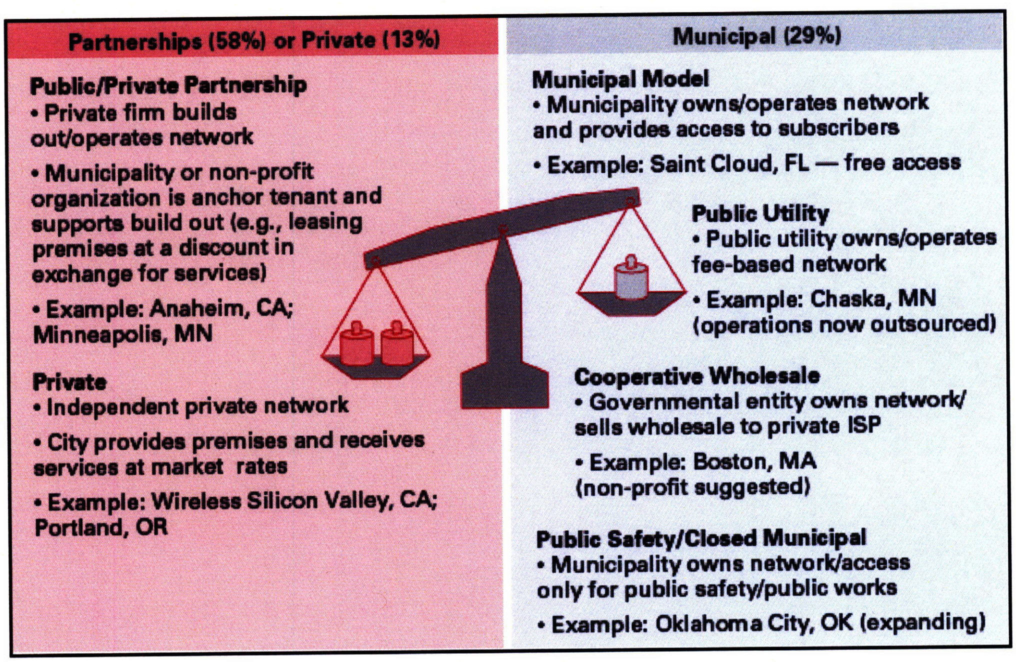

Figure 10: Municipality Wi-Fi Business Models[41]

- Network cost: Most municipalities either do not have the money, or they cannot justify the capital and operational expenditures for deploying a

[41] Sebastian, Ina, Corina Matiesanu, Michael Gartenberg, Joe Laszlo, and Julie Ask. "Municipal Wireless Update," Jupiter Research, Wi-Fi Mobility, Volume 3, 2006, pp. 6-24.

citywide network. In other cases, the network cost turn out to be much more than expected.

- Refusal of any anchor-tenant program: Some municipalities do not want to commit to any vendor for a length of time.

- Lack of customer model: Who are the customers? Customer identification has never been clear in the present business models.

- Lack of experience in implementing large mesh networks: Presently, there have not been many deployments with large mesh networks. Presently mesh network deployers are still learning as they go along.

- Negotiating delays, slow processes, and municipal demands: The process of implementing a mesh network is slow and drawn out. Access to poles and power may have to be negotiated for and voted upon by public boards or committees. Some municipalities try to impose all the risk-taking on the mesh network deployers.

- Competition: Major carriers and cable companies are against the deployment of wireless mesh networks. After all, wireless mesh networks takes away their customer base and lower their margins. WiMAX is also being pushed by some vendors as the next technology.

3.2 Municipal Case Studies:

The following case studies reinforce the issues mentioned above. And in the cases which seem to be succeeding, the model appears to be a public/private partnership where the municipality is an anchor tenant to the privately own network. Interestingly enough, the New Millennium Research Council in 2005 publish a report detailing why municipalities should *not* be providing Wi-Fi

Broadband services with public funds.[42] The New Millennium Research Council (NMRC) is an organization created in 1999. The NMRC's goal is to research real-world solutions to the problems and challenges confronting policy makers, primarily in the areas of telecommunications and technology. The Council consists of policy experts drawn from academia, think tanks, and other policy institutes nationwide.

3.2.1 EarthLink and San Francisco, CA:[43], [44]

EarthLink won the bid to implement city Wi-Fi within the city of San Francisco. The coverage area was 46 miles and the initial price projection was $10 million. Under the agreement of the original proposal, Google provides free Wi-Fi service of up to 300kbps in conjunction with its advertising platform within the coverage area, while EarthLink offers residential Wi-Fi service for $20. EarthLink in partnership with Google was to finance, deploy, and own the network.

Unfortunately, the venture between EarthLink and San Francisco fell apart.[45] EarthLink had wanted a 16 year anchor-tenant program. San Francisco wanted to shorten the plan to five years. Contract alterations between the city and the company were slow due to lack of communication. And when EarthLink had released a statement that the current business model would not provide an acceptable return, coupled

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42 New Millennium Research Council. "'Not In The Public Interest –The Myth of Municipal Wi-Fi Networks': Why Municipal Schemes to Provide Wi-Fi Broadband Service With Public Funds Are Ill-Advised," February 2005.

43 Earthlink, Google, and City and County of San Franscisco. "TechConnect Community Wireless Broadband Network Public Version," February 2006, pp. 12-23.

44 Sebastian, Ina, Corina Matiesanu, Michael Gartenberg, Joe Laszlo, and Julie Ask. "Municipal Wireless Update," Jupiter Research, Wi-Fi Mobility, Volume 3, 2006, p. 20.

45 Letzing, John. "Google-EarthLink San Francisco Wi-Fi on hold," http://www.marketwatch.com/news/story/google-earthlink-san-francisco-wi-fi-project, Marketwatch, August 2007.

with EarthLink's new policy of divesting away from municipal Wi-Fi, San Francisco ended its partnership with EarthLink.

3.2.2 Cheetah Wireless and Las Vegas, NV:

The original agreement was that Cheetah Wireless provides secured wireless services for Las Vegas Engineering Traffic Department. The Las Vegas Traffic Department was looking for a secure network to manage the traffic lights in over 500 intersections.[46] The opportunity opened up other avenues for mesh network applications in other municipal departments. Cheetah Wireless had planned to charge end-users at fixed Wi-Fi hotspots $20-$40 a month and business users $60-$80 a month anywhere within the coverage area. The contractual service with Cheetah Wireless grew into a pilot mesh program. Cheetah Wireless deployed and managed the program while the Las Vegas municipality took on an anchor tenancy. Estimated cost of operational expenditure per square mile came out to be $150,000 with anchor tenants reducing the cost by 75%. Capital expenditure was $37,500 per square mile.[47]

The program is still on going. There have been two major stumbling blocks. The first issue has been radio interference from existing Wi-Fi equipment. Since Wi-Fi occupies an unlicensed frequency, many businesses owners, including the airport have their own Wi-Fi/radio equipment operating at the same frequency. The second issue is keeping up with the demands of a growing city. Buildings are being constructed everywhere. A new building means more mesh nodes have to place around the area to circumvent the Wi-Fi signals around the construction.

4646 Cass, Stephen. "Viva Mesh Vegas," IEEE Spectrum, January 2005, pp. 48-53.

47 Horwitz, Jay and Ina Sebastian, "Cheetah Wireless Provides Las Vegas with Municipal and Commercial Access," Jupiter Research, 2005.

3.2.3 Galaxy Internet and Brookline, MA:

Galaxy Internet successfully won a bid to deploy, own, and operate a wireless network over Brookline, MA. The company will provide Wi-Fi services to residents and businesses at low cost, and free Wi-Fi services at various hot spots within the city. Galaxy also must lease network space for other Wi-Fi providers interested in offering Wi-Fi to the residences and businesses. Galaxy will be allowed the use of municipal assets, such as telephone poles.

In exchange, the city will have free access to the network for municipal applications. Municipal applications include real-time application support for public safety personnel and field staff. Future applications include intelligent devices for reporting utility usage.[48]

Presently, this project is still ongoing. So far the difficulties have yet been determined.

3.2.4 Corpus Christi, Texas:

Presently, the municipality owns and operates the wireless mesh network through a nonprofit organization, CC (Corpus Christi) Digital Community Development Corporation. Tropos Network in partnership with Northrop Grumman Corporation deployed approximately 1600 routers over 147 square miles (288,000 people). Coverage is estimated to about 90% of the population. Capital expenditures is expected to be at $7.1 million (includes equipment and backhaul), with installation cost at $1.1 million, and consultation fees at $0.5 million. Operational expense is

[48] Town of Brookline, "Municipal Wireless Broadband Initiative," Information Technologies Department, www.townofbrooklinema.com.

expected to be $600,000 annually with two-thirds of the amount going towards maintenance.[49]

Originally, the wireless mesh network consisted of 300 nodes and 37 backhaul access points, and was created for an automated meter reading system.[50] Municipal officials decided to expand the network for multiple uses. Applications include an emergency communication system for first responders and public safety, data access for municipal workers, community portal services, and free web access for residences. The municipality planned to be a wholesaler of bandwidth also.

Although the Corpus Christi was managing and operating the wireless network, the city has been looking for a partnership with the private sector. In 2007, the city agreed to sell to EarthLink the network for $5.3 million along with $340,000 in fees. And for ten years, the municipality will receive $300,000 in annual revenue. EarthLink would own, operate, and maintain the network. The company would charge $20 to residences for wireless high speed Internet access.[51]

However, a year later, with the announcement from EarthLink's CEO that the company will be divesting from Wi-Fi, Corpus Christi ends the contract with EarthLink. Under the one year of ownership by EarthLink, the company had paid the city $3.71 million, spent about $1.76 million in network improvements and $860,000 in radio equipment; the company had found some parts of the city had spotty wireless services. With the ending of the contract, the wireless mesh network is returned to

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49 Horwitz, Jay and Ina Sebastian, "Public Safety and Efficiency Drive Corpus Christi Deployment," Jupiter Research, 2005.

50 Pronto Networks, "Corpus Christi, TX, Pioneers Metro-Wide Wi-Fi Mesh Net: A Case Study," p. 4.

51 WRAL.LocalTechWire.com, "Earthlink Takes Over WiFi Network in Corpus Christi," http://www.wral.com/business/local_tech_wire/news/story/1227333, March 8 2007.

municipality ownership.[52,53] Corpus Christi, at this time, is reassessing its business model.

Corpus Christi had hoped originally to engage in a mixed public-municipality use network model owned by the municipality; the original plan was free wireless access for residences. Due to the lack of a clear business model, the municipality had difficulty in establishing a private partner. In addition, the coverage of the network did not meet up to expectations.

3.2.5 US Internet and Minneapolis, MN:

US Internet is investing $20 million into a wireless mesh network consisting of 2000 nodes of Belair equipment over 59 square miles in Minneapolis, MN. In return, the city government and public safety agents agree to pay US Internet $1.25 million annually for ten years to deploy and operate the network. In addition, US Internet can provide 1 Mbps download wireless service for residential users for $20/month, 3Mbps download service for $30/month, and 6Mbps download service for $35/month. Area coverage was last estimated to be about 85%.[54]

So far, the partnership, with Minneapolis as the anchor tenant, US Internet and Belair Networks deploying and operating the network, has been relatively successful. Recently, when the I-35 Bridge collapsed, emergency response crews employed the wireless mesh network for communications, real-time accesses to maps of the recovery site, and real-

52 Medford, Cassimir. "Corpos Christi Disconnects Earthlink," Red Herring, http://www.redherring.com/Home/24128, April 15, 2008.

53 Aguilar, Elvia. "Partnership with Earthlink may be cut off," Corpus Christi WiFi News," http://www.ccwifinews.com/blog/, April 15, 2008.

54 US Internet. "Minneapolis Selects US Internet for Citywide Wireless," http://www.usinternet.com/press-releases/Minneapolis-Selects-US-Internet.htm, September 5, 2006.

time video support to help with the recovery operation.[55] Of interest is the fact that the emergency response teams are using the 4.9 GHz public-safety spectrum. The nodes that are being positioned over Minneapolis are BelAir200 multiswitch routers which can deliver a combination of broadband speeds over Wi-Fi, WiMAX, cellular, and 4.9-GHz public-safety spectrums. As successful as the venture has been, there have been some issues with coverage area; people are reporting dead spots.

3.2.6 September 11, 2001 and Other Disasters:

Although the event of 9/11 had nothing to do with wireless mesh networks, the communication overload on that date reinforces the need for an alternative emergency communication system. Shortly, within the attack on the first World Trade Center buildings, the cellular phone network was overwhelmed with calls.[56] Wireless communications came to a stop. Whether terrorist acts or natural disasters like Katrina,[57] a self-healing communication network is necessary in the occurrence of such events.

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55 Thibodeau, Patrick. "New Wi-Fi network proves critical in Minneapolis bridge disaster," Computerworld Security, http://www.computerworld.com, August 3, 2007.

56 Wikipedia. "Communication during the September 11, 2001 attacks.," http://en.wikipedia.org/wiki/Communication_during_the_September_11%2C_2001_attacks, May 6, 2008.

57 Warrick, Joby. "Crisis Communications Remain Flawed," Washingtonpost.com, http://www.washingtonpost.com/wp-dyn/content/article/2005/12/09/AR2005120902039.html, December 10, 2005.

Chapter 4

A NEW BUSINESS MODEL

Earlier in Chapter 1, several metrics can be used to measure urban decline. This section explores how the system approach of implementing a wireless network within an urban setting affects these metrics in the short and long term. The most essential part of this approach is first improve the Wi-Fi business models derived from municipalities as it pertains to urban revitalization. Also a couple of the latest developments in network technology seem to help address the reoccurring issues of coverage and bandwidth in mesh deployment.

4.1 Redefining the Wi-Fi Business Model for Urban Renewal:

4.1.1 The Direct Customers:

Within a normal prospering city, the direct customers would be the residences of the city. However, marketing studies have shown that the majority of Internet users is within the age of 18-34 and falls within the medium to high income bracket. And with a city undergoing urban decline, statistics show that such a group is a small minority (See Chapter 1). The direct customers are then the municipality itself in an anchor-tenant program.

4.1.1.1 Emergency First Responders:

Emergency service units will benefit greatly with an emergency communication system in the event of a disaster. The wireless mesh network can make use of the 4.9 GHz spectrum reserved for public safety. A wireless mesh network can provide real-time data to the response teams during an emergency.

More interestingly is that emergency communication devices utilizing the 4.9 GHz spectrum would not interfere with the unlicensed Wi-Fi spectrum used by the rest of the wireless mesh network. In 2003, the FCC made available 50 MHz between 4.940 GHz and 4.990 GHz for licensing in the use of public safety. Any communications in this frequency band must be used for the purpose of protecting life, health, or property.[58] Table 27 shows the different channels and the center frequency for devices communicating within the 4.9 GHz spectrum and Table 28 depicts the maximum transmit power. The channels can be aggregated to bandwidths of 1, 5, 10, 15, or 20 MHz.

Center Frequency (MHz)	Channel Numbers	Channel Bandwidth (MHz)
4940.5	1	1
4941.5	2	1
4942.5	3	1
4943.5	4	1
4944.5	5	1
4947.5	6	5
4952.5	7	5
4957.5	8	5
4962.5	9	5
4967.5	10	5
4972.5	11	5
4977.5	12	5
4982.5	13	5
4985.5	14	1
4986.5	15	1
4987.5	16	1
4988.5	17	1
4989.5	18	1

Table 27: Frequency Channels for 4.9 MHz Spectrum[59]

58 Jacobsmeyer, Jay M., "An Introduction to 4.9 GHz," MRT Urgent Communications: Service, Safety, Security, http://mrtmag.com/rebanding/radio_introduction_ghz/, May 12, 2008.

59 Cisco Systems, "Overview-Cisco Support for 4.9 GHz Public Safety Broadband Spectrum in the United States," Whitepaper, 2005, pp. 2-3.

Channel Bandwidth (MHz)	Class A Peak Transmitter Power (dBm)	Class B Peak Transmitter Power (dBm)
1	20	7
5	27	14
10	30	17
15	31.8	18.8
20	33	20

Table 28: Peak Transmit Power of 4.9 MHz Devices[59]

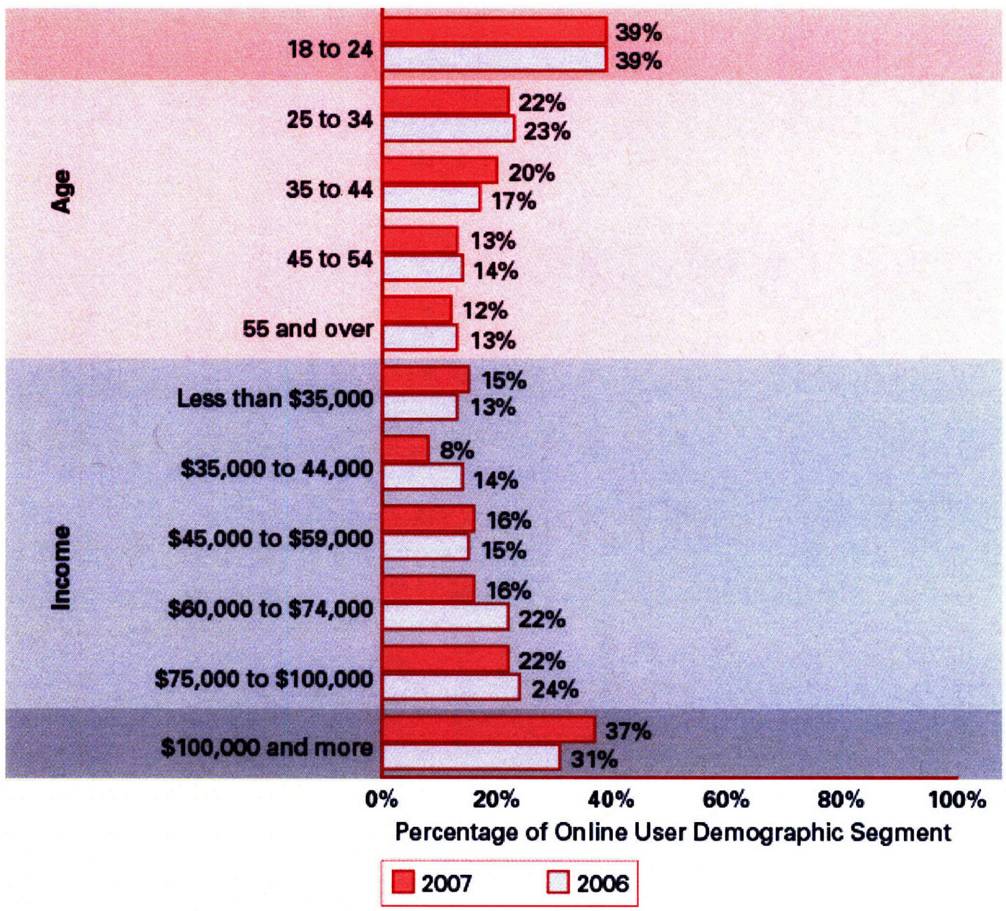

Figure 11: Statistics of Group Most Frequently Using the Internet[60]

[60] Sebastian, Ina, Ian Fogg, Corina Matiesanu, Ina Mitskaviets, and Julie Ask. "US Public WI-FI Consumer Survey, 2007, WISP Opportunities in the Consumer Space," Jupiter Research, 2007, p. 3.

4.1.1.2 *Law Enforcement:*

A city undergoing urban decline is often characterized by a high crime rate. High criminal activities hinder any areal economic development; most people are reluctant to open businesses in high crime areas. Crime also increases the tendency of a city's population to migrate away from the city.

Under a wireless mesh network, video surveillance cameras can be placed at high-crime areas. Law enforcement officers can also retrieve data real-time during field investigations. Studies by Kathryn McCollister are able to convert losses due to different crimes in terms of dollars.[61] Lowering crime statistics of urban areas within a few percentages can translate into thousands of dollars saved for communities. Table 29 shows the estimated cost associated with a particular crime. Tangible costs are defined as the direct costs that are quantifiable. Examples of tangible costs are the cost of the damage property, litigations, medical costs, etc. Intangible costs are much more difficult to quantify. An example of intangible costs is pain and suffering. More importantly, reducing the crime rates attract people back into urban areas.

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61 McCollister, Kathryn, "The Cost of Crime to Society: New Crime-Specific Estimates for Policy and Program Evaluation," http://www.tresearch.org/resources/AHSRPresentations/McCollister.ppt, University of Miami, April 22, 2008

Total Per-Offense Cost for Different Types of Crimes in 2004 Dollars			
Type of crime	Tangible costs only ($)	Intangible costs only ($)	Total per-offense cost ($)[a]
Murder[a]	$1,139,922	$7,352,983	$8,492,905
Rape/sexual assault	$25,954	$174,228	$200,037
Aggravated assault	$18,599	$101,336	$111,801
Robbery	$20,890	$27,755	$46,484
Arson	$6,267	$2,341	$8,405
Motor vehicle theft	$8,166	$178	$8,328
Household burglary	$3,663	$342	$3,974
Larceny/theft	$1,333	$12	$1,344
Stolen property offenses	$493	$0	$493
Vandalism	$449	$0	$449
Forgery and counterfeiting	$435	$0	$435
Embezzlement	$434	$0	$434
Fraud	$420	$0	$420

[a]Total per-offense costs calculated as the sum of tangible cost (excluding uncorrected risk-of-homicide costs) and intangible cost.

Table 29: Monetary Loss per Criminal Offense

4.1.1.3 *Libraries and other Community "Hot Spots":*

Libraries and conference areas often need access to Internet services or database information. These areas are frequently wired to an Internet Service Provider at the cost of approximately $60-$80 a month. A wireless mesh network can easily service such areas without the need of cables.

4.1.1.4 *Other Municipality Services:*

In a much similar manner to how the use of Wi-Fi expanded in Las Vegas' municipality departments, the same progression can occur across most municipalities. Most municipalities need a meter reading service for water billing. A wireless mesh network provides a very cost-effective solution. A municipality can gather water usage information from its residential consumers quickly through a wireless network. Or in a similar approach as to what Brookline in MA is attempting, build an entire wireless IT infrastructure to increase municipality efficiency. Various city departments can access in real-time pertinent information on the city to quickly perform their jobs. For example, law enforcement can quickly acquire the layout of an area before proceeding to the location.

4.1.1.5 *Other Wi-Fi Customers:*

Businesses: To successfully reverse the trend of any urban decline, much of the weight will fall upon the revitalization of the urban economy. A wireless mesh network can help facilitate business growth. Businesses can provide high speed Wi-Fi hotspots for consumers. Or more likely, the wireless mesh network can help create and sustain the "Mobile Marketing Ecosystem" for economic growth.[62] Figure 12 demonstrates the "Mobile Marketing Ecosystem". The system is a collaboration between advertisers, aggregators, content publishers, carriers, and industry organizations to engage the consumers. Each one of these five entities is specialized in a certain area and would be working in conjunction with the others to deliver through a wireless network higher quality content to the consumer than it would be possible if a single entity pursued at it alone.

[62] Acuff, Courtney. "Understanding the Mobile Marketing Ecosystem," http://www.clickz.com/showPage.html?page=3626938, ClickZ, September 6, 2007.

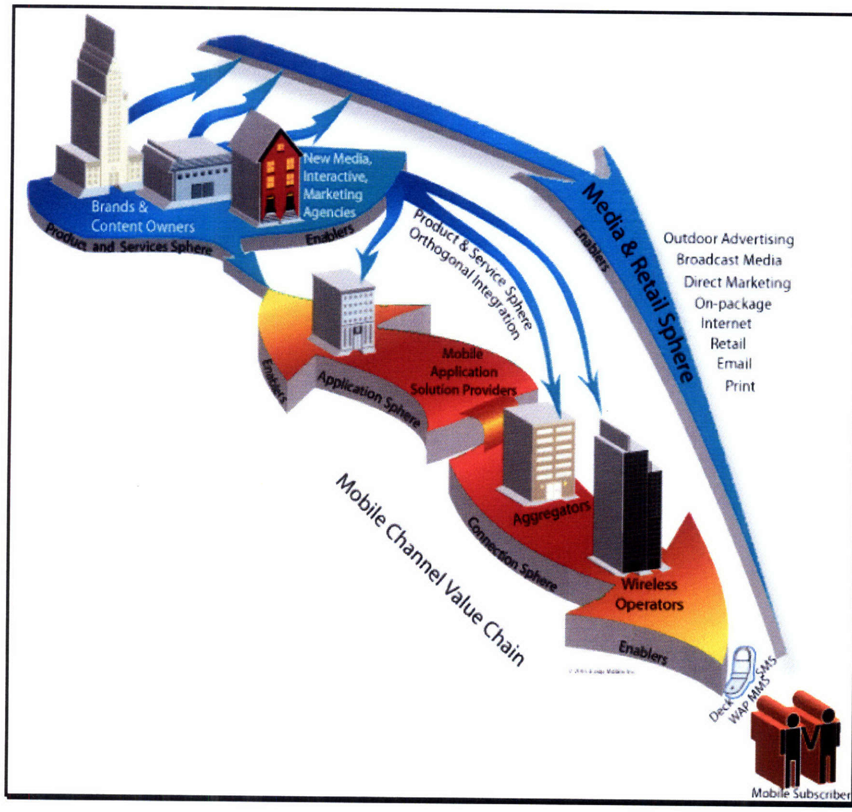

Figure 12: Mobile Marking Ecosystem[63]

4.1.2 Crossing the Digital Divide:

Statistics as shown in Figure 11 indicate that majority of Wi-Fi users are young consumers. However, the same statistics show that most low income families do not have broadband access. Broadband availability through a wireless mesh network in conjunction with a technology education program can help bridge the digital divide. Partially subsidized by an anchor-tenant program, Wi-Fi access can be brought to lower income families at substantially reduced prices when compared to wired broadband (See pricings provided in Lessons Learned). More

[63] Becker, Michael. "Research Update: Unfolding of the Mobile Marketing Ecosystem: A Growing Strategic Network," Mobile Marketing Association, http://mmaglobal.com/modules/article/view.article.php/74 , Oct 11, 2005.

importantly, when the wireless mesh network is implemented in conjunction with the $100 laptop,[64] the "seeds" of future Wi-Fi users are sown.

Although this return is more of a long term one, the growth in Wi-Fi demand will grow annually. High school students will learn how to access information on the Internet. They, in turn, will bridge their parents to the digital world. As time progresses, these high school students will become the higher human capital needed to reverse urban decline. The Boston case study previously demonstrated is a good example of the importance of an education system in urban revitalization.

4.2 Addressing Network Requirements

4.2.1 QOS: (Quality of Service):

The types of services provided by a wireless mesh network for an improved business model places certain requirements on the network. IP-based networks by nature do not protect bandwidth, nor guarantee timely arrival of packets and, depending on the type of applications, bandwidth and latency may be issues. For applications such as email, Web surfing, and ftp, "best effort" services are acceptable in an IP-based network. However, when the applications involve multimedia (such as video surveillance) and IT software such as ERP (Engineering Resource Planning), the network needs to protect the bandwidth and guarantee minimal latency. Table 30 shows the bandwidth and latency requirements that the network must meet for acceptable multimedia applications.

[64] The $100 laptop is part of the "One Laptop per Child" initiative started by Nicholas Negroponte with fellow associates from MIT Media Lab.

Application	Bandwidth	Latency	Frame Loss
Audio	64 Kbs - 1.5 Mbps	Higher tolerance to latency	Higher tolerance to frame loss
Video streaming	Higher requirement: 2 Mbps for SD and 20 Mbps for HD	Low	Higher tolerance to frame loss
Voice and Video conferencing	Lower requirement: voice < 32 Kbps; 128 Kbps for videoconferencing	Low (<50 ms)	Higher tolerance to frame loss
Gaming	Lower requirement: 32 Kbps – 128 Kbps	Lowest (< 10 ms)	Low tolerance to frame loss

Table 30: QOS Requirements[65]

4.2.2 New Standard and Working Drafts:[66]

In 2005, the IEEE ratified 802.11e which applies to QOS within an IP-based network. The IEEE committee is also presently working on two new standards, 802.11n and 802.11s. The two working drafts, once ratified, along with 802.11e will affect future wireless mesh networks in the areas of coverage and routing, and bandwidth, latency requirements for applications.

4.2.2.1 IEEE 802.11e:

802.11e enhances the MAC layer protocols for QOS improvements over wireless networks. More specifically, 802.11e replaces the PCF (Point Coordination Function) and the DCF (Distributed Coordination Function) with the Hybrid Coordination Function (HCF) within the MAC layer. The PCF and the DCF in the original MAC layer handles the channel accesses: sharing the wireless medium and collision detection during communications. Best effort is the only priority. On the other hand, the HCF consists of two modes of operation: Enhanced Distribution Coordinate Access (EDCA) and HCF

65 Intel, "Providing QoS in WLANs: How the IEEE 802.11e Standard QoS Enhancements Will Affect the Performance of WLANs," 2004,

66 Wikipedia. "IEEE 802.11e-2005," http://en.wikipedia.org/wiki/IEEE_802.11e, May 5, 2008.

Controlled Channel Access (HCCA) with QOS mechanisms that include optional protocols. Four classes are defined in each mode for priority: voice, video, best effort and background. Voice packets, in this order, would have the highest priority. The difference between the HCFCA and the EDCA is that the HCFCA allows more flexibility in scheduling and traffic management.

4.2.2.2 *IEEE 802.11n*[67,68]:

802.11n represents the next generation Wi-Fi standard. This new standard is actually a superset of the earlier standard 802.11a, and is backward compatible with 802.11b/g. 802.11n employs two techniques to increase data rate and coverage (See Table 26). The standard will utilize multiple receivers and transmitters, or MIMO (multiple-input multiple-output) and an increased PHY frequency.

MIMO allows antenna diversity, which permits parallel streams of data transmissions, or spatial multiplexing. This capability to utilize multiple antennas allows 802.11n receivers to recover message signals from multipath signals. Multipath signals are the reflected signals that arrive at the receiver after the line of sight (LOS) signal transmission has been received. This phenomenon would be common for mesh nodes surrounded by buildings. The older standards of 802.11 perceived multipath signals as interference that degraded a receiver's ability to recover the message information in the signal. MIMO technology fully exploits signal reflection to its advantage. Figure 13 displays a mesh node with MIMO technology.

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[67] Wikipedia. "IEEE 802.11n," http://en.wikipedia.org/wiki/IEEE_802.11n, May 5, 2008.

[68] Geier, Jim, "Multipath a Potential WLAN Problem," Wi-Fi Planet, http://www.wi-fiplanet.com/tutorials/article.php/1121691, May 14, 2002.

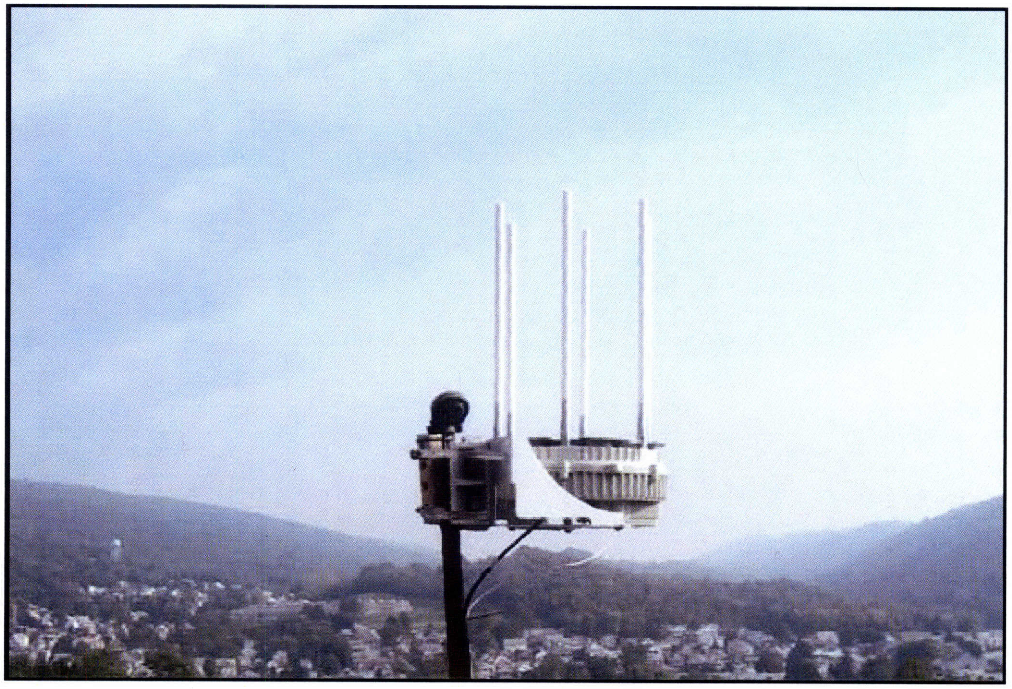

Figure 13: MIMO Mesh Node[69]

The increased frequency within the PHY allows for doubling the channel throughput. Legacy 802.11 PHY operation was limited to 20MHz. The new frequency is 40MHz.

The 802.11n standard will continue to incorporate OFDM (orthogonal frequency-division multiplexing) in the same manner as 802.11b/g. OFDM divides signal frequencies into several modulated channels for increased throughput. Coupling OFDM with MIMO technology and an increased PHY data transfer rate permits early 802.11n equipment to

[69] Wavion. "Case Study: Johnson Controls, Conxx, and Wavion, Provide Exceptional Services Funded By Savings," 2007, p. 1.

each theoretical maximum throughputs of 270Mbps to 300Mbps,[70] which opens up many types of network applications.

4.2.2.3 IEEE 802.11s:

802.11s is expected to be published in 2008. The goal of this draft is to build in interoperability standards for wireless mesh network vendors. Included in the draft are[71]

- Topology discovery.
- Path selection and forwarding.
- Channel allocation,
- Security,
- Traffic management,
- Network management.

Every wireless mesh network would have a default mandatory protocol HWMP (Hybrid Wireless Mesh Protocol). The goal is that a user can go from one wireless mesh network to another seamlessly.

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[70] Wexler, Joanie. "Throughput promise of 802.11n lies in 5GHz band," Network World, **http://www.networkworld.com/includes/ads-pre.html**, March 21, 2007.

[71] Murphy, Jim, and Ashok Saraf, "802.11s extends wireless outdoors," Network World, http://www.networkworld.com/news/tech/2006/041706-80211s-wireless.html, April 17, 2006.

Chapter 5

CONCLUSION

5.1 The Mesh Network Model:

The Urban Mesh Network Model is shown in Figure 14. By introducing mesh network technology into a declining area, opportunities to improve security, safety, education and the economy are created. Municipalities within declining urban areas may pursue the following path:

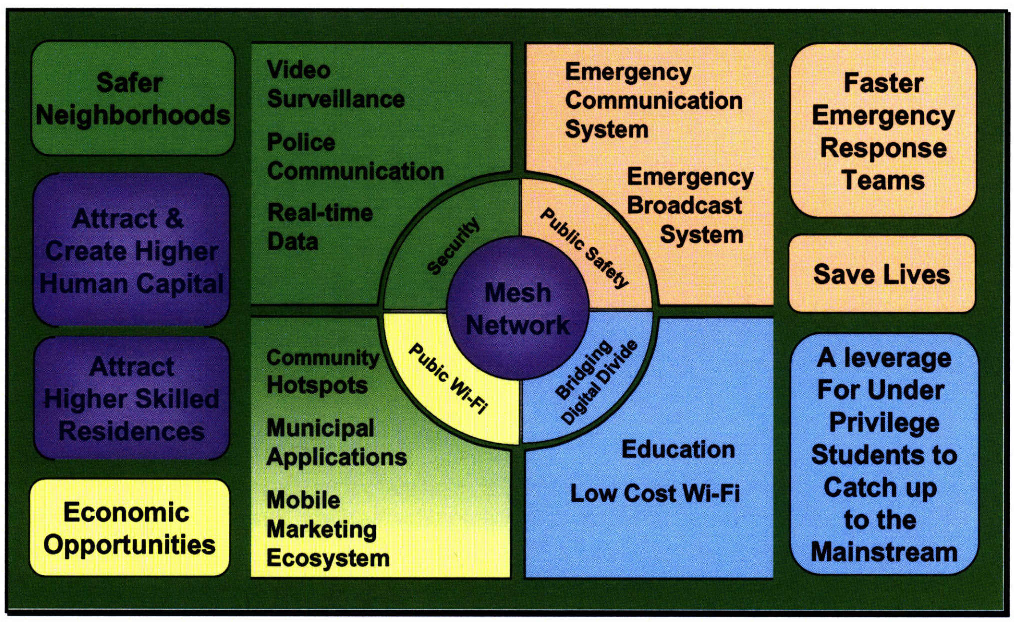

Figure 14: Mesh Network Model for Urban Area

1. Establish a sustainable and sound business model for mesh networks.

2. Implement Mesh Network as an anchor-tenant after carefully selecting a network deployer and Internet Service Provider.

3. Once the mesh network is established:

- Improve security through law enforcement and the latest in communication technology.

- Improve public safety coordination and communication through the mesh network.

- Provide a (wireless) network forum to encourage high technology research and development and promote economic opportunities.

- Educate junior high and high school students on computers and using the Internet.

- Provide low-cost Wi-Fi to residences.

The goals are to attract people back to the neighborhood and improve the education level of the residences. Security and economic opportunities will lure higher skilled people. Education in conjunction with initiatives such as the "One laptop per child" program will bridge the existing residences to the technological age. Urban decline will only reverse if the people who live and work there want and contribute to the change.

5.2 Further Studies:

This thesis provides a high level approach to an old issue. Further research can be made within the area of mesh deployment. More importantly, there are over three hundred municipality Wi-Fi initiatives underway. Studies can be made to determine the effects of Wi-Fi mesh networks on communities. Statistics will most likely reveal the importance of communication within the information age much akin to the roads and highway to the industrial age.

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