panOULU: Triple Helix Driven Municipal Wireless Network Providing Open and Free Internet Access

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ABSTRACT
This paper describes the birth, evolution and current status of a unique wireless city network provided by a consortium of municipalities, public research and educational institutions, and industry. The relevance of the network is illustrated with statistics of providing open and free Internet access to the general public and with R&D examples. The keys to the success of the network have included brave collaboration transgressing organizational boundaries, strong political and operative leadership, cost-effective outsourcing, and the 'KISS' principle in network design.

Keywords
WLAN, Wi-Fi, City, Knowledge, Innovation

INTRODUCTION
This paper tells a story of public research and educational institutions, municipalities, and private ISPs in the Oulu region in northern Finland joining forces to establish a large municipal wireless Network called panOULU (public access network OULU) (http://www.panoulu.net). In its coverage area the Network provides open (no authentication) and free (no payment) Internet access to general public. Over the past seven years the Network has become an indispensable asset to the community, both as an Internet access network and as a R&D resource.

The story is set against the backdrop of two concepts. The first concept is the triple helix model (THM) of academia-government-industry relations for innovation studies [10] as the Network is an innovation born from such relations, with the local University as the driver. Also, to boost local economy the key institutions in the Oulu region have formed so-called Oulu Innovation Alliance structured according to the THM, though many years after the founding of the Network. The second concept is municipal networking, as the Network is facilitated by exceptional contribution from the City of Oulu. However, in comparison to most other municipal networks ours is unique in terms of shared ownership and service offering.

We first introduce the triple helix model of academia-government-industry relations for innovation studies. Then we discuss recent key developments in municipal wireless networking, drawing up a simple taxonomy of the typical challenges faced by municipal wireless networks. We describe the founding and the 'grassroot' evolution of the Network in detail. In the current status of the Network we focus on the City of Oulu's motivation and investment. We illustrate the usage of the Network with statistics of providing open and free Internet access to the general public and with R&D examples. In the analysis we first discuss the manifestation of the THM in the innovation process underlying the Network. Then we look at how we have tackled the typical challenges of municipal wireless networks. We conclude with some lessons learned and the future outlook of the Network.

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Triple Helix Model for Innovation Studies
The triple helix model of academia-government-industry relations for innovation studies grew from the evolution in the dynamics between these institutions [10]. The starting premise was the traditional institutional differentiation: academia is associated with the generation of intellectual capital, government with the control of the public sphere, and industry with the creation of wealth. However, in the emergent networked knowledge-based society these roles have become intertwined. For example, industries are now important producers of new knowledge, while academia and cities are acting as organizers of regional innovation systems. Further, academia is now increasingly expected to economically support itself with revenues from selling knowledge to industries and government.

The triple helix of the three institutions ('selection environments') operating upon one another is developed along four dimensions: 1. internal transformation of the helices; 2. influence of one helix upon another; 3. creation of new overlay of institutional structures from the interaction between the three helices; and 4. recursive effect of these entities on themselves and on the larger society. The underlying communication is institutionally defined and functionally differentiated, so that the two levels operate upon each other selectively during processes of mutual adjustment.

THM emphasizes the role of the individual. When individuals from several institutions interact, they reflexively fine-tune communications with different value systems in the background, as expressions of diverse institutional traditions and manifold interests, which promotes creativity. Originating from the university, THM calls for academics to show leadership in the interaction.

THM also emphasizes the role of knowledge-based innovations in driving and disrupting the dynamics of economics and society. In THM jargon these are called 'spillovers', where new knowledge, technology, product or service spills over into initially unintended areas.

THM recognizes the cultural dimension of knowledge-based systems. 'Best practices' in academia-government-industry relations are not guaranteed to be transferable between nations or regions because the regulatory and legislative conditions specifying the government are subject to varying legal and cultural criteria. At regional level, tradeoffs between regional government, local academia and industry may shape specific advantageous niches. Leydesdorff and Deakin [11] studied THM in the context of urban technologies in 'smart cities', concluding that to become 'smarter', the cities must have sufficient intellectual capital and political leadership to become culturally and economically productive 'centres of creative slack'.

Municipal Wireless Networks

The concept of municipal wireless networking refers to a municipality playing a role in the provision of broadband network access in its territory with some wireless technology. In most cases these networks are deployed in cities, thus the alternate term wireless city networks. With the development of cheap wireless technologies, notably the IEEE 802.11 WLAN using unlicensed frequency spectrum and entering mass market in 2000, many municipalities started exploring and in some cases got involved in deploying wireless networks. Municipal networking boomed especially in North America, where 357 projects were announced by June 2006 [17]. The WLAN was a 'spillover', the disruptive knowledge-based innovation that allowed municipalities to challenge the 'cabelco' duopoly.

However, the boom ran into a roadblock soon after, when the technological and economical shortcomings of the projects were exposed [4] and compounded with legal obstacles. The telecommunication industry vehemently opposed municipal networks, arguing that municipal service provisioning is ineffective and that tax sponsored municipal networks do not compete on fair terms with commercial networks. The industry heavily lobbied policy makers which responded by installing legal restrictions on municipal networks [7].

Municipal wireless network projects have had a great diversity in terms of their objectives, technology choices and business models [2, 4, 19]. Ballon *et al.* [2] compared 15 wireless city initiatives either in operational or preparatory phase in the EU and in the US. Almost all initiatives were driven by city, excluding one private and two community initiatives. While at least three (Philadelphia, Portland and San Francisco) of the 15 initiatives have recently collapsed, the comparative study still provides a nice overview of the key trends in municipal wireless networking.

Municipal wireless networks are driven by different objectives. In Ballon's study the most frequent goals as stated in the policy and strategy documents of the 15 initiatives were: stimulate local economic fabric 12, bridge digital divide 10, platform for innovation and services 9, network for government personnel 9, platform for e-government services 8, support education 8, and support tourism 7. Only two initiatives stated increasing competition in broadband as their objective. While the EU initiatives emphasized stimulating economic development, the US initiatives emphasized bridging the digital divide.

14 of the 15 initiatives used the IEEE 802.11 WLAN technology. 10 initiatives employed it using the so-called mesh topology to provide large uniform outdoor coverage instead of just hotspots of individual access points. In half of the initiatives providing indoor coverage was also one of the objectives. Although the WLAN technology was never originally designed for building large wireless metropolitan area networks providing outdoor coverage, it soon became popular for that purpose due to availability of cheap and robust hardware and high penetration in user devices. The fact that WLAN uses the unlicensed 2.4 GHz ISM (Industrial, Scientific and Medical, IEEE 802.11b/g) and 5 GHz UNII (Unlicensed National Industrial Infrastructure, IEEE 802.11a) frequency bands was also a significant factor, as the municipalities did not have to worry about the availability and cost of frequency licenses.

The frequency license exemption has proved to be a double-edged sword, however. Since anyone can set up a WLAN network, hundreds of access points and user devices can be competing for the limited number of channels at a particular urban location. This leads to congestion and high packet loss due to interference, particularly on the 2.4 GHz band used by the more popular IEEE 802.11b/g technology and other technologies and devices such as Bluetooth radios and cordless phones. Thus, no quality of service can be guaranteed in practice. Consequently, in the US many municipalities have deployed wireless networks for public safety on the 4.9 GHz band reserved for that purpose. Further, many initiatives have badly overestimated WLAN's range and coverage in city centers with many tall buildings. In some initiatives the IEEE 802.16 WiMAX technology is used for wireless backhaul. It requires a license for a dedicated frequency, thus a particular quality of service can be guaranteed and for a much longer range.

Municipal wireless networks employ vastly different models in terms of contributions from the public and private sectors to network ownership and operation, and service provisioning. Ballon's study identified six different business models that incorporate different municipal inputs ranging from just site rental to full financing, ownership and operation of a network. Consequently, the municipalities obtain varying return of investment in terms of control and services ranging for example from just

limited amount of free usage by city employees to full control and completely free access to general public.

Several high profile and many smaller municipal wireless network projects have collapsed in the past few years. Breitbart *et al.* [3] documented the failure of the Wireless Philadelphia initiative. Hudson [8] provided a detailed account of the demise of several projects in California, including the San Francisco TechConnect initiative that fell apart before any network was built. St. Cloud in Florida, the first city in the US to provide free municipal wireless Internet access to residents and visitors alike suspended its Cyber Spot network, as the city council adjudged the annual maintenance expenses of reportedly ~600000$ to be too much given the state of the city's finances. Parallel, companies such as Earthlink and MetroFi discontinued their municipal wireless businesses. We synthesize these unfortunate stories into a simple taxonomy of the typical challenges of municipal wireless networks along five interrelated dimensions.

Societal challenges

The primary challenge is justifying why a municipality should be involved in the provisioning of wireless broadband Internet access. As discussed earlier, typical objectives range from bridging the digital divide to supporting education. However, if the goal is digital inclusion, why not just subsidize ISP provisioned (wired) broadband Internet connectivity to the homes of the underprivileged [8]? Another challenge is to determine where and to whom access should be provided: only public or also residential and industrial areas, only local residents or also visitors? The final challenge is to rigorously measure the societal impact of a municipal wireless network, once the network has been deployed.

Economical challenges

The primary challenge is to minimize the capital and operational expenditure of the network (from the municipality's point of view) and to maximize economic benefits, whether they are direct financial profits from subscriber fees or indirect gains from stimulating the local economic fabric. As discussed earlier, this is pursued by various business models incorporating different inputs from and outputs to the municipality. One big decision is whether network access is free of charge or not. Again, the final challenge is the measurement of success in economic terms.

Technical challenges

A municipal wireless network typically comprises of the following building blocks: access points (AP) establish wireless links with user devices; optional controllers manage the APs; wired/wireless backhaul network distributes the traffic between the APs and a core (backbone); the core provides various functions such as IP addressing and routing, DNS (Domain Name System), AAA (Authentication, Authorization and Accounting), traffic engineering and monitoring, and possibly various services such as a SMTP (Simple Mail Transfer Protocol) server for sending email; and Internet uplink (gateway) connects the network to the public Internet. Each building block comes with a number of sometimes challenging and costly decisions to be made in terms of technology, vendor, capacity, configuration, operation, maintenance, and renewal. We already discussed why the IEEE 802.11 WLAN has become the de facto link layer technology in municipal wireless networks and how it has sometimes been abused with unrealistic expectations in terms of technical performance. Interesting technical decisions include optional encryption of the wireless links, optional authentication of the users, and whether to make any promises on the quality of service (e.g. throughput and coverage), for example. Again, the final challenge is the measurement of success in technical terms.

Legal challenges

The legal challenges can take different forms depending on the type of network ownership, business model and network access granted to the users. We already referred to the legislative regulations that some states and countries have installed on municipal provisioning of broadband networks based on the policy that municipalities should not compete with private industries. In some cases a municipality can be interpreted to be an ISP that brings along its own legal responsibilities. In some countries providing access without user authentication may be prohibited on the grounds of preventing terrorism, for example.

Political challenges

Considering the many tough challenges discussed so far, a municipal wireless network needs strong political support to succeed. The city's top political figures, e.g. the mayor, have to 'champion' the network, willingly adopting strong political ownership and leadership. Similarly, the key operative persons involved with the network, e.g. municipal civil servants such as the CIO (Chief Information Officer), have to 'champion' the network, show operative leadership. Without such leadership a municipal network can quickly become mired in political quicksand [3, 8].

FOUNDING AND EVOLUTION OF THE NETWORK

The City of Oulu with 140000 citizens is the sixth largest city in Finland. The multidisciplinary University of Oulu of ~16000 students, the Oulu University of Applied Sciences (later Polytechnic) of ~9000 students and a large campus of the VTT Technical Research Centre of Finland are located in the City. These organizations and the City of Oulu's pro R&D economic policies have played key roles in transforming the Oulu region into a well-known 'silicon valley' with 17400 hi-tech jobs and 800 hi-tech companies. The Oulu region of 225000 inhabitants had the highest regional R&D investment per capita (4800 €, 13 % of regional GDP) in Europe in 2009.

RotuaariWLAN - R&D Seed

The University's R&D activities played an important role in convincing the community, particularly the City, about the vision of a wireless city network. In fall 2001 a

Professor at the University started preparing a new research project on future context-aware mobile multimedia services [12]. The services to be evaluated "in the wild" outdoors at downtown required proper wireless broadband Internet connectivity to be effective. However, GPRS (General Packet Radio Service), the emerging mobile data technology of that time could only provide dismal data rates of few tens of kbps with large connection setup latencies and round-trip delays. While not really intended for outdoor use, the IEEE 802.11b with its 11 Mbps nominal data rate and small latencies was the only viable technology to provide the required wireless broadband Internet connectivity at downtown. Further, Internet access could be provided without any SIM cards and billing mechanisms.

In fall 2002 the Professor's research group installed at its own expense the first six APs around the Rotuaari walking street at the heart of the city, thus the name RotuaariWLAN for this zone. The incumbent ISP contributed telephone lines for the backhaul of the APs, as a part of their sponsorship to the research project. The City provided sites for APs in public buildings. Additional sites were obtained from private properties with agreements vesting the research party with the responsibility for paying the electricity consumption of the APs. A letter of support signed by the Mayor, the Chancellor of the University, the Chair of the Oulu Business Coalition and a Director of Nokia was available to persuade property companies. A major WLAN hardware vendor donated a pair of LRE (Long Reach Ethernet) switches for establishing LRE links to the APs over the telephone lines. The outdoor network had expanded to 11 APs by June 2003, when the research project officially started and invested additional nine APs for a total of 20 by fall 2003.

In a parallel development, the Professor's department was deploying a wireless network on the University campus with the IEEE 802.11b technology, facilitated by an internal research infrastructure grant obtained by the Professor and industrial sponsorship. The campus network totaled of 110 APs by fall 2003. Similarly, the Network Manager (NM) of the Polytechnic had started deploying a wireless network on their campus with first ten APs installed by fall 2003.

In addition to the RotuaariWLAN at downtown, another notable factor in motivating the City administration into deploying WLAN in public premises was, somewhat surprisingly, a location-aware library service developed for the University library [1]. The service highlighted the benefits of equipping a public library with a WLAN. Consequently, the City selected the City Library as the first public premise that was furnished with ten APs in summer 2003. The DM (Development Manager) and the newly appointed CIO of the City played a key role in this development.

Founding of the panOULU Consortium

The operative personnel of the four aforementioned organizations got together in July 2003 for the first joint meeting to discuss the establishment of a joint wireless network. Prior the meeting the Professor and the NM authored the first proposal of the organizations pooling their WLAN networks into a virtual joint network. Access to the joint network would be granted via a roaming agreement between the organizations. The NM deserves the credit for the cost-efficient design of the roaming via cross authentication of existing user accounts with an access controller donated by a large mobile phone manufacturer.

An important part of the preparation was the consortium agreement that would dictate issues such as network architecture, ownership, operation, business model and governance. The Network was deemed to comprise of two principal building blocks, organization specific visitor networks typically implemented with WLAN, and core services including Internet uplink. The Professor's team at the University would provide and maintain the core services while the Incumbent ISP would sponsor the Internet uplink. Each organization would retain the ownership and remain responsible for the expenses and the management of its own visitor network. The consortium would have a two-tiered governance structure comprising of an administrative group and a technical group. The Professor was appointed as the University's representative in the administrative group and adopted the chair's post.

When the consortium agreement was signed in Oct 2003, the Network totaled the 150 APs mentioned before (University 110, RotuaariWLAN 20, Polytechnic 10, City 10). The APs advertised the same SSID 'panoulu', thus they appeared belonging to the same network. Access to the Network required a web-based login with a user account granted by any of the four organizations. In the City's case the user account was the number of a library card with the associated PIN serving as the password. The consortium also prepared vouchers containing fixed-term guest accounts to be distributed to visitors.

Evolutionary Milestones

Competence Oulu 400 program released (Apr 2005)

In celebration of its 400th anniversary the City released so-called Competence Oulu 400 program. The DM and the CIO played key roles in spearheading the preparation of the program, together with an expert group comprising of the Professor, the NM and industrial representatives. The Mayor persuaded the City Council to sponsor the 2.5 M€ two and a half year program from the City's strategic funds. The program comprised of nine development and training projects. One of them was allocated 651 k€ investment budget to expand the City's WLAN zone by 400 APs. The placement of the APs was guided by a questionnaire to the City's divisions and citizens could also propose places to be covered. The Professor served as the part-time project manager of the network expansion project and the CIO provided strategic guidance. The in-house

project team was formed by recruiting three unemployed persons with some technical background. The City's IT division arranged backhaul connections while cabling was outsourced. The expansion included 60 AP WLAN mesh zone for blanketing the city center with outdoor coverage. The Professor's team at the University tested different WLAN mesh products and advised the City in preparing the public tender to procure the WLAN mesh. The contract was awarded to a Regional ISP that incidentally deployed the mesh with the hardware that had been found to be superior in the preceding testing by the University. Upon announcing the program the Mayor also challenged the community, particularly the private sector, to join the Network project.

Open access by removal of user authentication (Jun 2005)
After some contemplation the consortium decided to get rid of user authentication in June 2005. While the main practical benefit of authentication were the statistics collected by the access controller, the benefits of removing authentication appeared far more prominent. First and foremost was improved usability as the users would no longer have to enter their usernames and passwords, which was particularly cumbersome with emerging WLAN smart phones. When authentication was removed, the usage of the Network doubled immediately.

'Network subscription' concept is published (Feb 2006)
The 'Network subscription' is an ISP product offered currently by four ISP's. By purchasing it the subscriber can acquire into its premises a Network hotspot providing open and free Internet access, together with a regular business subscription to the subscriber's own use [13]. The Professor designed the concept for two reasons. First, to offer the ISPs with an incentive to join the Network project instead of turning against it. Second, to have a mechanism for expanding the coverage into private premises with private funding, as public funds were restricted to furnishing public premises. The Professor offered the concept to all six ISP's active in the Region, of which three decided to productize the concept, the Incumbent ISP, a small Local ISP and a large National ISP. The latter two thus became the second and third ISPs in the consortium. The National ISP bought into the concept because one of their big customers in the City wanted to have the Network in their premises. The Professor recruited 11 spearhead customers that signed up to purchasing the 'Network subscription'. The Mayor used his clout to round up the local business elite to the public release of the concept at the City Hall. The concept was branded as the tool for the private sector to respond to the challenge of joining the Network project that the City had presented upon releasing the Competence Oulu 400 program. Interestingly, another national ISP having its own commercial WLAN hotspot product, and thus understandably electing not to productize our concept, openly attacked the Network at the event.

VTT Technical Research Centre of Finland joins consortium (May 2006)
VTT is a national entity with a large site in the City. In 2005 VTT decided to cease operating their in-house visitor WLAN themselves and contracted an external ISP for that purpose. VTT's IT administration in the headquarters in the capital region wanted each site to use the external ISP, which among other things required user authentication. However, the IT manager of the local VTT site fought back and succeeded in negotiating an exception that allowed the local VTT site to join the consortium.

City Council grants budget funding to Network (Nov 2007)
Till the conclusion of the Competence Oulu 400 program at the end of 2007, the City's investment into the Network had always been project funding. As the project funding was running out, the CIO and the DM proposed the City's IT budget in 2008 to include 300 k€ allocation for Network related activities. The City Council's favorable decision was eased by political heritage: they wanted to secure the future of the network that they themselves had launched by granting funding to the Competence Oulu 400 program. This was a crucial step in ensuring long-term financial support from the City, for staying in the budget book is much easier than getting there in the first place.

Pulmonary Association HELI joins consortium (Feb 2008)
Pulmonary Association HELI has large premises in the City, providing among other things educational services and hosting conferences. The NM installed a Network hotspot into a conference hall for such an event in 2007. The feedback from the attendees of the event was so positive that HELI soon decided to furnish its premises with the Network and officially joined the consortium in Feb 2008.

Regional ISP joins consortium (Jun 2008)
The Regional ISP having won the contract for the mesh productized the 'Network subscription' and officially joined the consortium in Jun 2008 as the fourth ISP.

Regional Network gets funding (Oct 2008)
In 2008 the City started preparing a proposal for a two-pronged regional expansion of the Network. First, the City invited the ten nearby Townships to join the initiative. Second, local companies with mobile WiMAX products heavily lobbied the City to include the deployment of a regional mobile WiMAX network in the initiative. In Oct 2008 the proposal received funding from the ERDF with co-funding from the eight Townships joining the initiative. The expansion of the WLAN network was procured via a public tender soliciting a WLAN controlled based solution. The installation of 204 APs was kicked off in June 2009 and successfully completed by Nov 2009. However, the deployment of the regional mobile WiMAX network failed for several reasons. The network hardware manufacturer had difficulties in providing functional base stations in a timely fashion. The handset manufacturer discontinued their mobile WiMAX handset product line. The City foresaw problems in renewing the experimental fixed-term

frequency license granted by regulatory authorities. These issues convinced the parties to cancel the deployment after hundreds of thousands of tax euros had been burned but just four of the planned 13 base stations were installed. This constitutes the biggest failure of the Network project so far, largely due to the poor risk analysis of the companies.

Current Status

The Network comprises of two main parts, the original 'City' Network and the recent 'Regional' expansion. The 'City' comprises of two basic types of WLAN zones, the visitor networks of the five public organizations and the 'Network subscriptions' sold by four ISPs. The WLAN zones are aggregated in layer 2 with a straightforward 'KISS' design [13]. The 'City' part has 1064 APs contributed by individual providers as follows: City 546, University 280, Polytechnic 90, HELI 53, VTT 22, RotuaariWLAN 10, and 'Network subscriptions' sold by the ISPs 63. They have been purchased by organizations such as the local airport, a large technology center operator, a large training and management institute, a large sports complex, a large bank, several media and IT companies, and many cafes, pubs and restaurants. Most subscribers advertise the availability of the Network in their premises by posting the logo of the Network at their front entrance.

The 'Regional' part comprises of the WLAN zones of eight nearby Townships around the City. The WLAN zones are independent IP subnets which are aggregated in network layer. The 'Regional Network' has in total 204 APs located in key public buildings such as city halls, libraries and schools. It also has two mesh zones, 8 APs on a large camping area and 4 APs on a golf course. Each municipality has its own WLAN controller that manages the APs of that municipality.

All APs advertise the SSID 'panoulu' and use the core services sponsored by the City and maintained by the University. In some zones the APs also advertise other logical networks (SSIDs) such as 'eduroam' on the University and Polytechnic campuses. The City purchases the 100 Mbps Internet uplink from the Polytechnic that retails it from the Incumbent ISP.

OukaWLAN – City's of Oulu's Wireless Zone

When exploring the City's motivation to invest in municipal wireless, we have to keep in mind that the Region has 100% availability of economic broadband Internet in residential areas. Thus municipal wireless is not driven by residential access or by digital divide. The national government provides communications to police and fire departments, thus municipal wireless is not motivated by public safety as in the US. Further, economic high quality mobile voice service is available from many telcos, thus municipal wireless is not driven by VoIP.

The City has a triangular knowledge society strategy comprising of three components: infrastructure; services and applications; and skills and readiness. The wireless network improves access to services and applications, as long as the citizens have the skills and readiness to use both assets. For this purpose the Competence Oulu 400 program also established a citizens' portal of e-services and executed a number of training programs.

"Open wireless network is a civil right"
CIO Ilari Heikkinen, City of Oulu

The above statement by the former CIO underlines how the City administration regards open and free wireless Internet access at public service points and areas as municipal infrastructure just like public libraries. Nomadic or mobile wireless access regardless of time and place is a tool for e-government services and workforce mobility, increases productivity and competitiveness, improves the well-being of residents and visitors, and supports local R&D and innovation environment, thus contributing to staying on the leading edge. Incidentally, in Oct 2009 Finland became the first country in the world to declare broadband Internet access a legal right. The ISPs in Finland were expected to provide all Finnish citizens with a broadband Internet connection of at least 1 Mbps starting July 2010. The plan is to raise the speed to 100 Mbps by 2015.

The OukaWLAN has currently 546 APs, which provide indoor coverage in pretty much all public buildings and outdoor coverage at downtown and other selected locations such as sports centers. In some places such as the city hospital, the 28 APs are employed to establish two logical networks, hidden and secure network providing wireless access to patient databases for hospital staff, and open and free Internet access for patients and visitors. The OukaWLAN includes a mesh zone of 58 APs at downtown and 2 mesh APs at a sports center. The mesh zone at downtown has 5 root APs, which provide wireless backhaul links to other mesh nodes on the 5 GHz band using the IEEE 802.11a technology. Thus just 5 fixed backhaul connections are needed for 58 APs, which means respective savings in backhaul expenses. The OukaWLAN has also few mobile APs for example in mobile libraries.

The City's capital expenditure can be reliably estimated from the 651 k€ investment budget of the Competence Oulu 400 program. 356 k€ were used for 346 enterprise grade standalone APs (1029 €/AP) and 295 k€ for 60 mesh APs (4917 €/AP), including antennas, other accessories and installation expenses. These unit costs with current AP counts brings the total capital investment to 807 k€ (5.8 € per capita). For comparison per capita estimates of other municipal wireless networks [5]: Corpus Christi (US) $23, Westminster (UK) $48 and Scottsburg (US) $64. It should be noted that these are per capita estimates, not per area.

In 2010 the City's operational expenditure on the 'City' Network was 102.8 k€. It covered the backhaul for APs (retailed by City's IT division that purchases them partly from the Incumbent ISP, 47.0 k€), AP maintenance (outsourced to two companies via public tender, 40.5 k€), Internet uplink (purchased from the Polytechnic, 6.0 k€), and computer room facilities for the servers running the core services (provided by City's IT division, 9.3 k€). It

should be noted that the expense budget contains no salaries for dedicated network staff in the City administration that has spelled problems in terms of operative ownership of Network related matters.

USAGE OF THE NETWORK

Open and Free Internet Access to General Public

In its coverage area the Network provides open (no login, authentication or registration) and free (no payment) wireless internet access to the general public with a WLAN-equipped device. The first HTTP request of a particular device on a given day is redirected to a splash page providing basic information about the Network, including a reminder of the fact that the Internet connection provided by the Network is not secure, i.e. the wireless link is not encrypted. So far security has not been a problem. We monitor the network traffic and if a device emits traffic patterns typical to viruses, e.g. lots of successive ARP queries, we blacklist the device temporarily. When the device connects the next time, it is directed to a webpage notifying the user about the potential virus. Excluding the blocking of outgoing port 25 (SMTP) required by national legislation, there are no restrictions on the use of the Network. The connection is provided 'as is' - no promises are made on the quality of service. The effective throughput varies depending on location and network congestion, typically ranging from few hundred kbps to few Mbps.

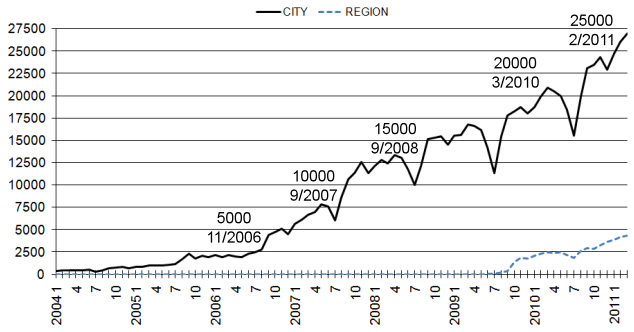

Figure 1. Number of unique devices using the Network.

Figure 1 shows the number of unique devices using the 'City' and 'Regional' Networks in every month. A unique device is identified by its unique MAC address. The 'valleys' in the 'City' Network correspond to summer months when the University and Polytechnic campuses are quiet. Till the end of year 2007 the growth is to a large extent explained by the expansion of the Network. However, since then the growth is explained by WLAN devices, particularly smart phones, becoming increasingly popular. In April 2011, 26982 unique devices used the 'City' Network, totaling 689145 sessions and 19.0 million minutes of online time. The statistics include only 850 of the 1064 APs due to technical issues. Up to 30% of users are visitors, as determined from device ID's and network usage patterns. As discussed earlier, one motivation is to provide visitors with convenient and free Internet access. It is particularly useful for international visitors, given the exorbitant international roaming charges for mobile data.

R&D Resource

The Network is a valuable R&D resource thanks to its large coverage and open and free Internet access. The Network has been employed in numerous technology pilots and research projects for studying topics such as mobility management [16], context-aware multimedia services [12] and pervasive gaming [18]. R&D is supported with various resources such an advanced packet analysis system for inspecting data flows in the Network. We briefly discuss three pilots highlighting the City's R&D collaboration with industry.

Nokia conducted its first public UMA (Unlicensed Mobile Access) pilot in the Network in Jun-Sep 2006 in collaboration with the Incumbent ISP, the City and the University. UMA is a technology standardized by the 3GPP, now known as GAN (Generic Access Network). The purpose of the pilot was to evaluate the UMA technology in authentic urban setting. An UMA-enabled dual-mode handset was configured to access GSM core services over the Network if it was available, otherwise cellular network was used. 60 UMA-phones were distributed to the City staff that used the phones for three months, totaling 1.03 million seconds in the Network.

The City started a Mobile IP pilot with Fujitsu and Secgo (later acquired by Birdstep) in Sep 2006. Mobile IP is a mobility management protocol standardized by IETF. Selected City's mobile workers were given laptops equipped with multiple network interfaces including WLAN. A Mobile IPv4 client was installed into each laptop, to transparently and seamlessly select the best of the available networks, together with a built-in VPN for secure access to the City's intranet. The Network was configured to be the preferred wireless network if it was available. Thus a mobile worker, e.g. a home care nurse visiting elderly around the city, did not have to worry about network settings, but could always access the customer database safely from her laptop. The successful one-year pilot led to the City purchasing a production system. Today the City furnishes all new laptops with a MIP/VPN client.

In 2009 the City executed a web banner advertising trial limited to its own WLAN zone together with a company providing such a system. When a user device launched a web browser, a banner would float in the upper edge of the browser, showing both commercial advertisements brokered by the company and the City's announcements. As expected, the banner was resented by most users. The great revenues promised by the company never materialized and the trial was terminated after six months.

The Network provides backhaul connectivity to two new wireless networks, panOULU BT and panOULU WSN deployed by the University at downtown in fall 2010. The BT network is used for providing context-aware mobile multimedia services to mobile devices over no-cost BT technology and for modeling traffic flows from BT traces. The WSN network provides multi-hop half-duplex connectivity for low power sensors using the IEEE

802.15.4 radio on the 868 MHz band and the 6LoWPAN protocol stack. The first WSN pilots focus on automated metering and environmental monitoring.

ANALYSIS

Manifestation of the Triple Helix Model

The foundation and evolution of the Network are very concrete results of the collaboration between the local academia, the local government and industry. The dynamics of the underlying innovation process exhibit many THM characteristics. The intellectual leadership has come from the University and the Polytechnic, and the political leadership from the City. The process has been driven by the interaction between the individuals at respective institutions having committed themselves to the Network. The academia has inflicted a profound change on the government (City and nearby eight Townships) and the industry (ISPs providing 'Network subscriptions' and organizations purchasing them). When the City establishes a new public facility, it is by default furnished with the Network. These days the City employees rarely connect their laptops to a fixed LAN, but instead use the Network with the MIP/VPN client. The interaction between the organizations has created a new institutional overlay, the Network consortium, which convenes twice a year to stimulate interaction and to steer the innovation process.

The diffusion of our innovation of providing open and free Internet access with a municipal wireless network is characterized by the many municipal and industrial delegations visiting Oulu to learn about the Network. Some of them have then proceeded to deploy their own, for example the City of Kuusamo purchased from the Regional ISP a 'Network subscription' of 10 APs into selected public premises. A large municipality of over 2 million citizens in South Africa is a 'twin city' of the City. To sign the MOU between the twin cities, their large delegation visited the City in 2007 and among other things learned of the Network. With financial support from the Finnish government based on the collaboration with the City, they opened in 2010 the first eight hotspots in municipal libraries and community centers to provide open and free Internet access. The hotspots have made an immediate impact, attracting thousands of users, of which some travel as far as 40 km away. However, THM acknowledges that best practices are not necessarily transferable between regions. A region in southern Finland has a similar multi-provider network, but with mandatory user authentication that effectively reduces the usage of the network. A person promoting removal of authentication invited our CIO to give a presentation on the benefits of open and free Internet access to their consortium. However, other persons insisting on authentication would not budge.

Keys to Success

We briefly summarize the key features that have helped in tackling the challenges discussed in the introduction.

Triple helix of municipalities, academia and industry

Nine municipalities, four public research and education organizations, and four ISPs and their customers have engaged in a process of mutually beneficial leveraging of their network resources to establish the shared Network for the benefit of the community. The collaboration spreads the societal impact and reduces the economic burden of individual organizations. Many regions elsewhere have similar institutional networks, but they are not open to the community. Why so many public universities funded by tax payers have closed wireless campus networks? The 'Network subscription' provides the ISPs with an incentive to join the Network project instead of turning against it and expands the network to private premises.

'Champions' providing political and operative leadership

This story would have never unfolded without the commitment and contribution of selected individuals, notably the Mayor, the Professor, the NM, the DM and the CIO. Such 'champions' motivated by the benefit of the community are a must-have resource for a network that is not driven by direct financial profits.

Cost effective outsourcing of operations and maintenance

The City's operational expenditure of 102.8 k€ in 2010 corresponds to 0.01% of the City's annual budget and 0.06 € per citizen per month. It is a smart investment for a public service that anyone can use for free and that is used by ~25000 devices every month. Why do so many cities insist that a municipal wireless network should not cost anything to the city, when at the same time the same city pays top dollar for fiber? The City has cost-effectively outsourced functions such as AP maintenance to private businesses via public tenders. Given the current costs of these contracts it makes very little sense for the City to maintain its own network staff.

Involve R&D

The R&D activities conducted in the Network have played an important role in demonstrating the benefits of the Network, motivating the R&D organizations to contribute to the Network and securing further R&D investments into the Region, thus stimulating local economic fabric. The R&D organizations also provide in-house technical expertise and critical thinking in assessing commercial products and solutions.

Have realistic expectations on WLAN's capabilities and provide wireless coverage where it matters

We have learned that while it is fairly easy and cost efficient to deploy high quality indoor hotspots with the IEEE 802.11 WLAN, establishing large uniform outdoor coverage with quality of service guarantees is practically impossible on a license exempt frequency band. Therefore, we have not burdened our Network with a significant role in municipal service production. Now the Network is only used for the backhaul of few video surveillance cameras in places where fixed backhaul cannot be provided cost-effectively. Many municipal wireless networks have been launched with the ambitious objective of providing large

uniform coverage in urban areas and have ended up paying dearly for not being able to deliver. We have adopted a less ambitious approach, providing coverage in those public places and service points where it is deemed useful. Some ISPs have argued that general public would not want to use a WLAN of patchy coverage and uneven quality of service, but our network is proving these claims unjustified.

'KISS' network design to provide open and free access

Legislative and policy issues aside, providing open and free access comes with many benefits. It increases the usage and thus the impact of the network. It reduces costs and simplifies technical implementation, as no AAA is needed. Incidentally, in Mar 2011 Finland changed its national legislation so that it is no longer criminal to use an open WLAN without the consent of the owner. We do not encrypt the wireless link, which again would be a needless administrative and technical complication for little gain. Instead, we assume that the providers of services requiring strong authentication and privacy (e.g. online banks) also provide proper end-to-end security. We do not take a payment for access, as it would establish a conclusive contract with the user which would burden us with a range of legal responsibilities such as committing to a particular service level that would be difficult and costly to deliver. We also do not have to provide and maintain a billing system. All these decisions contribute to the 'KISS' design minimizing the number of moving parts in the network which minimizes costs and technical trouble in the long run.

Publicly report data on network usage

Surprisingly few municipal wireless networks provide any public data on the usage of the network, not even the successful ones. The networks with paying customers probably claim the data to be a commercial secret. A very modest usage is better left unreported? We have collected and openly reported comprehensive data on the usage of our Network from the very beginning. The data have been helpful in illustrating the impact and justifying the municipal investment.

Challenges

Rigorous assessment of the socioeconomic impact

Although we have a plenty of anecdotal and qualitative evidence on the impact of the Network, we would like to conduct a more analytic assessment of its socioeconomic impact on the Region with other regions as a baseline [9]. Although the proof on macroeconomic impact of broadband Internet is generally difficult to obtain, largely due to the lack of comprehensive data with sufficiently long time series, we have started developing a regional growth model that would allow assessing the socioeconomic impact of various factors including the Network.

Legal status and public policy

Our consortium model is not recognized as such by our current national legislation governing ISPs. The Finnish Communications Regulatory Authority published in Aug 2007 a memo that interpreted the current legislation with respect to wireless city networks and community networks implemented with WLAN. Such a network providing Internet access to an unlimited user population is regarded to constitute a public telecommunication network. This in turn imposes responsibilities in terms of registering the network with the regulators, technical quality of the network, user rights and information security. We have adopted a laissez-faire attitude to deal with these responsibilities.

Managing user expectations and media

We have learned in a painful manner that management of user expectations and media is very important. When the City announced the Competence Oulu 400 program, including the expansion of the Network by 400 APs in public service areas, a senior reporter of the local main newspaper intentionally twisted the press release into a front page story implying that the City promises to provide free residential Internet access to each and every citizen. The reckless 'journalism' resulted in confusion, citizens calling the City and the local ISPs to inquire when they can cancel their home Internet subscriptions. After that the newspaper has repeatedly twisted the facts to tarnish the Network. While we do not understand the motivation behind this 'journalistic' policy, it is certainly hurting our Network that is effectively based on the goodwill of the consortium members.

Help desk of a multi-provider Network

In our multi-provider Network many organizations have APs at downtown. When users have problems with access, they call the City's help desk. However, since all APs advertise the same SSID, neither the user nor the help desk staff have any easy way of telling in whose zone the problem may reside to initiate corrective action. While the number of such inquiries is rather small, the inability to address them efficiently has lead to unnecessary dissatisfaction among the City's help desk staff.

Future Outlook

Municipal WLAN vs mobile data in wireless Internet access

Municipal WLAN has been found to top 3G in realizing Internet access for a limited geographical area [15]. In our recent measurements the average quality of service of our Network was better than that of the 3.5G (HSPA, High Speed Packet Access) networks in our region. However, the upcoming 3.9G (LTE, Long Term Evolution) and 4G (LTE Advanced) networks may tip the balance. First 3.9G networks are operational boasting impressive data rates. But the increased wireless throughput combined with the rapidly growing population of wireless Internet users poses serious backhaul problem to ISPs. Most ISPs have resorted to capped data plans as a weak attempt to curb backhaul traffic. In a recent test of Verizon's new LTE network it took whopping 32 minutes for an LTE client to consume the 5 GB of data included in the cheapest monthly data plan [14]. Every byte downloaded thereafter would be much more expensive relatively speaking. This is hardly the user

experience desired by customers. The recently standardized IEEE 802.11n technology using multiple antennas with the MIMO (Multiple Input Multiple Output) technology benefits from multi-path propagation and reflections so prominent in urban environments and gives a new lifeline for WLAN in municipal wireless [6]. The City and the University have already started using IEEE 802.11n APs. In the long run ISPs will integrate 4G and WLAN since it is unreasonable to route the web surfing traffic of smart phones via the mobile core. The Wi-Fi Alliance launched in Mar 2011 a 'Hotspot Program' initiative that will improve the offloading of cellular data onto WLAN.

Policy on provisioning open and free Internet access

Citing prevention of terrorism, several countries have installed legislation that requires each Internet user to be authenticated by the ISP providing the access. This trend may eventually lead to a situation where providing open Internet access is deemed illegal. That would be a great loss to our Network and to our community.

CONCLUSION

Our network shows how public and private organizations can ally to provide open and free wireless Internet access to the benefit of the community. Strong political and operative leadership, cost-effective outsourcing, R&D, and the 'KISS' principle in network design and provisioning of access have been the other keys to success.

However, our network has evolved in a relatively small and cohesive community with a special pro R&D culture. As of now there is no evidence that our approach would scale up to larger cities with different policies and cultural settings.

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