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Alternative Network Deployments. Taxonomy, characterization, technologies and architectures
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Abstract

This document presents a taxonomy of "Alternative Network deployments", and a set of definitions and shared properties. It also discusses the technologies employed in these network deployments, and their differing architectural characteristics.

The term "Alternative Network Deployments" includes a set of network access models that have emerged in the last decade with the aim of bringing Internet connectivity to people, using topological, architectural and business models different from the so-called "traditional" ones, where a company deploys or leases the network infrastructure for connecting the users, who pay a subscription fee to be connected and make use of it.

Several initiatives throughout the world have built large scale alternative Networks, using predominantly wireless technologies (including long distance) due to the reduced cost of using the unlicensed spectrum. Wired technologies such as fiber are also used in some of these alternate networks. There are several types of alternate networks: community networks, which are self-organized and decentralized networks wholly owned by the community; networks owned by individuals who act as wireless internet service providers (WISPs); networks owned by individuals but leased out to network operators who use them as a low-cost medium to reach the underserved population, and finally there are networks that provide connectivity by sharing wireless resources of the users.

The emergence of these networks can be motivated by different causes such as the reluctance, or the impossibility, of network operators to provide wired and cellular infrastructures to rural/remote areas. In these cases, the networks have self sustainable business models that provide more localized communication services as well as Internet backhaul support through peering agreements with traditional network operators. Some other times, networks are built as a complement and an alternative to commercial Internet access provided by "traditional" network operators.

The present classification considers different existing network models such as Community Networks, open wireless services, user-extensible services, traditional local Internet Service Providers (ISPs), new global ISPs, etc. Different criteria are used in order to build a classification as e.g., the ownership of the equipment, the way the network is organized, the participatory model, the extensibility, if they are driven by a community, a company or a local stakeholder (public or private), etc.

According to the developed taxonomy, a characterization of each kind of network is presented in terms of specific network characteristics related to architecture, organization, etc.

Status of This Memo

This Internet-Draft will expire on January 2, 2016.

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1. Introduction

Several initiatives throughout the world have built large scale networks that are alternative to the traditional network operator deployments using predominantly wireless technologies (including long distance) due to the reduced cost of using the unlicensed spectrum. Wired technologies such as fiber are also used in some of these alternate networks. There are several types of alternate deployments: community networks are self-organized and decentralized networks wholly owned by the community; networks owned by individuals who act as wireless internet service providers (WISPs); networks owned by individuals but leased out to network operators who use such networks as a low cost medium to reach the underserved population, and finally there are networks that provide connectivity by sharing wireless resources of the users.

The emergence of these networks can be motivated by different causes, as the reluctance, or the impossibility, of network operators to provide wired and cellular infrastructures to rural/remote areas [Pietrosemoli]. In these cases, the networks have self sustainable business models that provide more localized communication services as well as Internet backhaul support (i.e. uplink connection) through peering agreements with traditional network operators. Some other times, they are built as a complement and an alternative to commercial Internet access provided by "traditional" network operators.

One of the aims of the Global Access to the Internet for All (GAIA) IRTF initiative is "to document and share deployment experiences and research results to the wider community through scholarly publications, white papers, Informational and Experimental RFCs, etc." In line with this objective, this document is intended to propose a classification of these "Alternative Network Deployments". This term includes a set of network access models that have emerged in the last decade with the aim of bringing Internet connectivity to people, following topological, architectural and business models different from the so-called "traditional" ones, where a company deploys the infrastructure connecting the users, who pay a subscription fee to be connected and make use of it. The document is intended to be largely descriptive providing a broad overview of initiatives, technologies and approaches employed in these networks. Research references describing each kind of network are also provided.

1.1. Traditional networks

In this document we will use the term "traditional networks" to denote those sharing these characteristics:

- Regarding scale, they are usually large networks spanning entire regions.

- Top-down control of the network and centralized approaches are used.

- They require a substantial investment in infrastructure.

- Users in traditional networks tend to be passive consumers, as opposed to active stakeholders, in the network design, deployment, operation and maintenance.

1.2. Criteria for the classification of Alternative Networks

The classification of Alternative Network Deployments, presented in this document, is based on the next criteria:

1.2.1. Commercial model / promoter

The entity (or entities) or individuals promoting an Alternative Network can be:

- o a community of users

- o a public stakeholder

- o a private company

- o crowdshared approaches are also considered

- shared infrastructure

- they can be created as a testbed by a research or academic entity

1.2.2. Goals and motivation

Alternative networks can also be classified according to the underlying motivation for them, i.e., addressing deployment and usage hurdles:

- reducing initial capital expenditures (for the network and the end user, or both)

- providing additional sources of capital (beyond the traditional carrier-based financing)

- reducing on-going operational costs (such as backhaul or network administration)

- leveraging expertise

- reducing hurdles to adoption (digital literacy; literacy, in general; relevance, etc.)

- extending coverage to underserved areas (users and communities)

- network neutrality guarantees

1.2.3. Administrative model

- centralized

- distributed

1.2.4. Technologies employed

- normal Wi-Fi

- Wi-Fi modified for long distances (WiLD), either with CSMA/CA or with an alternative TDMA MAC [Simo_b]

- 802.16-compliant systems over non-licensed bands

- Dynamic Spectrum Solutions (e.g. based on the use of white spaces)

- satellite solutions

- low-cost optical fiber systems

1.2.5. Typical scenarios

The scenarios where Alternative Networks are usually deployed can be:

- urban
- rural
- rural in developing countries

2. Classification of Alternative Networks

This section classifies Alternative Networks (ANs) according to their intended usage. Each of them has different incentive structures, maybe common technological challenges, but most importantly interesting usage challenges which feeds into the incentives as well as the technological challenges.

At the beginning of each subsection, a table is presented including a classification of each network according to the criteria listed in the "Criteria for the classification of Alternative Networks" subsection.

2.1. Community Networks

Commercial model/promoter	community
Goals and motivation	reducing hurdles; to serve underserved areas; network neutrality
Administration	distributed
Technologies	Wi-Fi, optical fiber
Typical scenarios	urban and rural

Table 1: Community Networks' characteristics summary

Community Networks are large-scale, distributed, self-managed networks sharing these characteristics:

- They are built and organized in a decentralized and open manner.

- They start and grow organically, they are open to participation from everyone, sometimes sharing an open peering agreement.

Community members directly contribute active (not just passive) network infrastructure.

- Knowledge about building and maintaining the network and ownership of the network itself is decentralized and open. Community members have an obvious and direct form of organizational control over the overall operation of the network in their community (not just their own participation in the network).

- The network can serve as a backhaul for providing a whole range of services and applications, from completely free to even commercial services.

Hardware and software used in Community Networks can be very diverse, even inside one network. A Community Network can have both wired and wireless links. Multiple routing protocols or network topology management systems may coexist in the network.

These networks grow organically, since they are formed by the aggregation of nodes belonging to different users. A minimum governance infrastructure is required in order to coordinate IP addressing, routing, etc. An example of this kind of Community Network is described in [Braem]. These networks follow a participatory model, which has been shown effective in connecting geographically dispersed people, thus enhancing and extending digital Internet rights.

The fact of the users adding new infrastructure (i.e. extensibility) can be used to formulate another definition: A Community Network is a network in which any participant in the system may add link segments to the network in such a way that the new segments can support multiple nodes and adopt the same overall characteristics as those of the joined network, including the capacity to further extend the network. Once these link segments are joined to the network, there is no longer a meaningful distinction between the previous and the new extent of the network.

In Community Networks, the profit can only be made by services and not by the infrastructure itself, because the infrastructure is neutral, free, and open (traditional Internet Service Providers, ISPs, base their business on the control of the infrastructure). In Community Networks, everybody keeps the ownership of what he/she has contributed.

Community Networks may also be called "Free Networks" or even "Network Commons" [FNF]. The majority of Community Networks accomplishes the definition of Free Network, included in the next subsection.

2.1.1. Free Networks

A definition of Free Network (which may be the same as Community Network) is proposed by the Free Network Foundation (see http://thefnf.org) as:

"A free network equitably grants the following freedoms to all:

Freedom 0 - The freedom to communicate for any purpose, without discrimination, interference, or interception.

Freedom 1 - The freedom to grow, improve, communicate across, and connect to the whole network.

Freedom 2- The freedom to study, use, remix, and share any network communication mechanisms, in their most reusable forms."

The principles of Free, Open and Neutral Networks have also been summarized (see http://guifi.net/en/FONCC) this way:

- You have the freedom to use the network for any purpose as long as you do not harm the operation of the network itself, the rights of other users, or the principles of neutrality that allow contents and services to flow without deliberate interference.

- You have the right to understand the network, to know its components, and to spread knowledge of its mechanisms and principles.

- You have the right to offer services and content to the network on your own terms.

- You have the right to join the network, and the responsibility to extend this set of rights to anyone according to these same terms.

2.2. Wireless Internet Service Providers WISPs

Commercial model/promoter	company
Goals and motivation	to serve underserved areas; to reduce CAPEX in Internet access
Administration	centralized
Technologies	wireless, unlicensed frequencies
Typical scenarios	rural

Table 2: WISPs' characteristics summary

WISPs are commercially-operated wireless Internet networks that provide Internet and/or Voice Over Internet (VoIP) services. They are most common in areas not covered by incumbent telcos or ISPs. WISPs often use wireless point-to-point or point-to-multipoint in the unlicensed frequencies but licensed frequency use is common too especially in regions where unlicensed spectrum is either perceived as crowded or where unlicensed spectrum may have regulatory barriers impeding its use.

Most WISPs are operated by local companies responding to a perceived market gap. There is a small but growing number of WISPs, such as AirJaldi [Airjaldi] in India that have expanded from local service into multiple locations.

Since 2006, the deployment of cloud-managed WISPs has been possible with companies like Meraki and later OpenMesh and others. Until recently, however, most of these services have been aimed at industrialized markets. Everylayer [Everylayer], launched in 2014, is the first cloud-managed WISP service aimed at emerging markets.

2.3. Shared infrastructure model

Commercial model/promoter	shared: companies and users
Goals and motivation	to eliminate a CAPEX barrier (to operators); lower the OPEX (supported by the community); to extend coverage to underserved areas
Administration	distributed
Technologies	wireless in non-licensed bands and/or low-cost fiber
Typical scenarios	rural areas, and more particularly rural areas in developing regions

Table 3: Shared infrastructure characteristics summary

In conventional networks, the operator usually owns the telecommunications infrastructures required for the service, or sometimes rents these infrastructures to other companies. The problem arises in large areas with low population density, in which neither the operator nor other companies have deployed infrastructure and such deployments are not likely to happen due to the low potential return of investment.

When users already own a deployed infrastructure, either individually or as a community, sharing that infrastructure with an operator represents an interesting win-win solution that starts to be exploited in some contexts. For the operator, this supposes a significant reduction of the initial investment needed to provide services in small rural localities because the CAPEX is only associated to the access network, as renting capacity in the users' network for backhauling supposes is only an increment in the OPEX. This approach also benefits the users in two ways: they obtain improved access to telecommunications services that would not be otherwise accessible, and they can get some income from the operator that helps to afford the network's OPEX, particularly for network maintenance.

One clear example of the potential of the "shared infrastructure model" nowadays is the deployment of 3G services in rural areas in which there is a broadband rural community network. Since the inception of femtocells, there are complete technical solutions for low-cost 3G coverage using the Internet as a backhaul. If a user or community of users has an IP network connected to the Internet with some capacity in excess, placing a femtocell in the user premises benefits both the user and the operator, as the user obtains better coverage and the operator does not have to support the cost of the infrastructure. Although this paradigm was conceived for improved indoor coverage, the solution is feasible for 3G coverage in underserved rural areas with low population density (i.e. villages), where the number of simultaneous users and the servicing area are small enough to use low-cost femtocells. Also, the amount of traffic produced by these cells can be easily transported by most community broadband rural networks.

Some real examples can be referenced in the European Commission FP7 TUCAN3G project, (see http://www.ict-tucan3g.eu/) which deployed demonstrative networks in two regions in the Amazon forest in Peru. In these networks [Simo_a], the operator and several rural communities have cooperated to provide services through rural networks built up with WiLD links [WiLD]. In these cases, the networks belong to the health public authorities and were deployed with funds come from international cooperation for telemedicine purposes. Publications that justify the feasibility of this approach can also been found in that website.

2.4. Crowdshared approaches, led by the people and third party stakeholders

Commercial model/promoter	community, public stakeholders, private companies
Goals and motivation	sharing connectivity and resources
Administration	distributed
Technologies	wireless
Typical scenarios	urban and rural

Table 4: Crowdshared approaches characteristics summary

These networks can be defined as a set of nodes whose owners share common interests (e.g. sharing connectivity; resources; peripherals) regardless of their physical location. They conform to the following approach: the home router creates two wireless networks: one of them is normally used by the owner, and the other one is public. A small fraction of the bandwidth is allocated to the public network, to be employed by any user of the service in the immediate area. Some examples are described in [PAWS] and [Sathiaseelan_c]. Other example is constituted by the networks created and managed by City Councils (e.g., [Heer]).

In the same way, some companies [Fon] develop and sell Wi-Fi routers with a dual access: a Wi-Fi network for the user, and a shared one. A user community is created, and people can join the network in different ways: they can buy a router, so they share their connection and in turn they get access to all the routers associated to the community. Some users can even get some revenue every time another user connects to their Wi-Fi spot. Other users can just buy some passes in order to use the network. Some telecommunications operators can collaborate with the community, including in their routers the possibility of creating these two networks.

As in the case of main Internet Service Providers in France, Community Networks for urban areas are conceived as a set of APs sharing a common SSID among the clients favouring the nomadic access. For users in France, ISPs promise to cause a little impact on their service agreement when the shared network service is activated on clients' APs. Nowadays, millions of APs are deployed around the country performing services of nomadism and 3G offloading, however as some studies demonstrate, at walking speed, there is a fair chance of performing file transfers [Castignani_a], [Castignani_b]. Scenarios studied in France and Luxembourg show that the density of APs in urban areas (mainly in downtown and residential areas) is quite big and from different ISPs. Moreover, performed studies reveal that aggregating available networks can be beneficial to the client by using an application that manages the best connection among the different networks. For improving the scanning process (or topology recognition), which consumes the 90% of the connection/reconnection process to the Community Network, the client may implement several techniques for selecting the best AP [Castignani_c].

A Virtual Private Network (VPN) is created for public traffic, so it is completely secure and separated from the owner's connection. The network capacity shared may employ a low priority, a less-than-best-effort or scavenger approach, so as not to harm the traffic of the owner of the connection [Sathiaseelan_a].

The elements involved in a crowd-shared network are summarized below:

- Interest: a parameter capable of providing a measure (cost) of the attractiveness of a node towards a specific location, in a specific instance in time.

- Resources: A physical or virtual element of a global system. For instance, bandwidth; energy; data; devices.

- The owner: End users who sign up for the service and share their network capacity. As a counterpart, they can access another owners' home access for free. The owner can be an end user or an entity (e.g. operator; virtual operator; municipality) that is to be made responsible for any actions concerning his/her device.

- The user: a legal entity or an individual using or requesting a publicly available electronic communications' service for private or business purposes, without necessarily having subscribed to such service.

- The Virtual Network Operator (VNO): An entity that acts in some aspects as a network coordinator. It may provide services such as initial authentication or registering, and eventually, trust relationship storage. A VNO is not an ISP given that it does not provide Internet access (e.g. infrastructure; naming). A VNO is neither an Application Service Provider (ASP) since it does not provide user services. Virtual Operators may also be stakeholders with socio-environmental objectives. They can be a local government, grass root user communities, charities, or even content operators, smart grid operators, etc. They are the ones who actually run the service.

- Network operators, who have a financial incentive to lease out the unused capacity [Sathiaseelan_b] at lower cost to the VNOs.

VNOs pay the sharers and the network operators, thus creating an incentive structure for all the actors: the end users get money for sharing their network, the network operators are paid by the VNOs, who in turn accomplish their socio-environmental role.

2.5. Testbeds for research purposes

Commercial model/promoter	research / academic entity
Goals and motivation	research
Administration	centralized initially, but it may end up in a distributed model.
Technologies	wired and wireless
Typical scenarios	urban and rural

Table 5: Testbeds' characteristics summary

In some cases, the initiative to start the network is not from the community, but from a research entity (e.g. a university), with the aim of using it for research purposes [Samanta], [Bernardi].

The administration of these networks may start being centralized in most cases (administered by the academic entity) and may end up in a distributed model in which other local stakeholders assume part of the network administration [Rey].

3. Scenarios where Alternative Networks are deployed

Alternative Network Deployments are present in every part of the world. Even in some high-income countries, these networks have been built as an alternative to commercial ones managed by traditional network operators. This section discusses the scenarios where Alternative Networks have been deployed.

3.1. Digital Divide and Alternative Networks

Although there is no consensus on a precise definition for the term "developing country", it is generally used to refer to nations with a relatively lower standard of living. Developing countries have also been defined as those which are in transition from traditional lifestyles towards the modern lifestyle which began in the Industrial Revolution. When it comes to quantify to which extent a country is a developing country, the Human Development Index has been proposed by the United Nations in order to consider the Gross National Income (GNI), the life expectancy and the education level of the population in a single indicator. Additionally, the Gini Index (World Bank estimate) may be used to measure the inequality, as it estimates the dispersion of the national income (see http://data.worldbank.org/indicator/SI.POV.GINI).

However, at the beginning of the 90’s the debates about how to quantify development in a country were shaken by the appearance of Internet and mobile phones, which many authors consider the beginning of the Information Society. With the beginning of this Digital Revolution, defining development based on Industrial Society concepts started to be challenged, and links between digital development and its impact on human development started to flourish. The following dimensions are considered to be meaningful when measuring the digital development state of a country: infrastructures (availability and affordability); ICT (Information and Communications Technology) sector (human capital and technological industry); digital literacy; legal and regulatory framework; and content and services. The lack or less extent of digital development in one or more of these dimensions is what has been referred as Digital Divide. This divide is a new vector of inequality which - as it happened during the Industrial Revolution - generates a lot of progress at the expense of creating a lot economic poverty and exclusion. The Digital Divide is considered to be a consequence of other socio-economic divides, while, at the same time, a reason for their rise.

In this context, the so-called "developing countries", in order not to be left behind of this incipient digital revolution, motivated the World Summit of the Information Society which aimed at achieving "a people-centred, inclusive and development-oriented Information Society, where everyone can create, access, utilize and share information and knowledge, enabling individuals, communities and peoples to achieve their full potential in promoting their sustainable development and improving their quality of life" [WSIS], and called upon "governments, private sector, civil society and international organizations" to actively engage to accomplish it [WSIS].

Most efforts from governments and international organizations focused initially on improving and extending the existing infrastructure in order not to leave their population behind. As an example, one of the goals of the Digital Agenda for Europe [DAE] is "to increase regular internet usage from 60% to 75% by 2015, and from 41% to 60% among disadvantaged people."

Universal Access and Service plans have taken different forms in different countries over the years, with very uneven success rates, but in most cases inadequate to the scale of the problem. Given its incapacity to solve the problem, some governments included Universal Service and Access obligations to mobile network operators when liberalizing the telecommunications market. In combination with the overwhelming and unexpected uptake of mobile phones by poor people, this has mitigated the low access indicators existing in many developing countries at the beginning of the 90s [Rendon].

Although the contribution made by mobile network operators in decreasing the access gap is undeniable, their model presents some constraints that limit the development outcomes that increased connectivity promises to bring. Prices, tailored for the more affluent part of the population, remain unaffordable to many, who invest large percentages of their disposable income in communications. Additionally, the cost of prepaid packages, the only option available for the informal economies existing throughout developing countries, is high compared with the rate longer-term subscribers pay.

The consolidation of many Alternative Networks (e.g. Community Networks) in high income countries sets a precedent for civil society members from the so-called developing countries to become more active in the search for alternatives to provide themselves with affordable access. Furthermore, Alternative Networks could contribute to other dimensions of the digital development like increased human capital and the creation of contents and services targeting the locality of each network.

3.2. Urban vs. rural areas

The Digital Divide presented in the previous section is not only present between countries, but within them too. This is specially the case for rural inhabitants, which represents approximately 55% of the world’s population, from which 78% inhabit in developing countries. Although it is impossible to generalize among them, there exist some common features that have determined the availability of ICT infrastructure in these regions. The disposable income of their dwellers is lower than those inhabiting urban areas, with many surviving on a subsistence economy. Many of them are located in geographies difficult to access and exposed to extreme weather conditions. This has resulted in the almost complete lack of electrical infrastructure. This context, together with their low population density, discourages telecommunications operators to provide similar services to those provided to urban dwellers, since they do not deem them profitable.

The cost of the wireless infrastructure required to set up a network, including powering it (e.g. via solar energy), is within the range of availability if not of individuals at least of entire communities. The social capital existing in these areas can allow for Alternative Network set-ups where a reduced number of nodes may cover communities whose dwellers share the cost of the infrastructure and the gateway and access it via inexpensive wireless devices. Some examples are presented in [Pietrosemoli] and [Bernardi].

In this case, the lack of awareness and confidence of rural communities to embark themselves in such tasks can become major barriers to their deployment. Scarce technical skills in these regions have also been pointed as a challenge for their success, but the proliferation of urban Community Networks, where scarcity of spectrum, scale, and heterogeneity of devices pose tremendous challenges to their stability and the services they aim to provide, has fuelled the creation of robust low-cost low-consumption low-complexity off-the-shelf wireless devices which make much easier the deployment and maintenance of these alternative infrastructures in rural areas.

3.3. Gap between demanded and provided communications services

Beyond the Digital Divide, either international or domestic, there are many situations in which the market fails to provide the information and communications services demanded by the population. When this happens permanently in an area, citizens may be compelled to take a more active part in the design and implementation of ICT solutions, hence promoting Alternative Networks.

3.4. Topology patterns followed by Alternative Networks

Alternative Networks, considered self-managed and self-sustained, follow different topology patterns [Vega]. Generally, these networks grow spontaneously and organically, that is, the network grows without specific planning and deployment strategy and the routing core of the network fits fairly well a power law distribution. Moreover, the network is composed of a high number of heterogeneous devices with the common objective of freely connecting and increasing the network coverage. Although these characteristics increase the entropy (e.g., by increasing the number of routing protocols), they have resulted in an inexpensive solution to effectively increase the network size. One example corresponds to Guifi.net [Vega] with an exponential grow rate in the number of operating nodes during the last decade.

Regularly rural areas in these networks are connected through long-distance links (the so-called community mesh approach) which in turn convey the Internet connection to relevant organisations or institutions. In contrast, in urban areas, users tend to share and require mobile access. Since these areas are also likely to be covered by commercial ISPs, the provision of wireless access by Virtual Operators like [Fon] may constitute a way to extend the user capacity (or gain connection) to the network. Other proposals like Virtual Public Networks [Sathiaseelan_a] can also extend the service.

4. Technologies employed

4.1. Wired

In many (developed or developing) countries it may happen that national service providers may decline to provide connectivity to tiny and isolated villages. So in some cases the villagers have created their own optical fiber networks. It is the case of Lowenstedt in Germany [Lowenstedt], or some parts of Guifi.net [Cerda-Alabern].

4.2. Wireless

The vast majority of the Alternative Network Deployments are based on different wireless technologies [WNDW]. Below we summarize topics to be considered in such deployments. Different considerations about the available options are presented, including physical and Media Access Control (MAC) layers. In addition, the trends (and some recommendations) when using these features in Alternative Networks are summarized.

4.2.1. Antennas

Three kinds of antennas are suitable to be used in these networks: omnidirectional, low-gain directional and high-gain directional antennas.

For local access, omnidirectional antennas are the most useful, since they provide the same coverage in all directions of the plane in which they are located. Above and below this plane, the received signal will diminish, so the maximum benefits are obtained when the client is at approximately the same height as the Access Point.

For indoor clients, omnidirectional antennas are generally fine, because the numerous reflections normally found in indoor environments negate the advantage of using directional antennas.

For outdoor clients, directional antennas can be quite useful to extend coverage to an Access Point fitted with an omnidirectional one.

When building point-to-point links, the highest gain antennas are the best choice, since their narrow beamwidth mitigates interference from other users and can provide the longest links [Flickenger], [Zennaro].

Despite the fact that the free space loss is directly proportional to the square of the frequency, it is normally advisable to use higher frequencies for point-to-point links when there is a clear line of sight, because it is normally easier to get higher gain antennas, the protection against interferences is better and the spectrum saturation is lower. Deploying high gain antennas at both ends will more than compensate for the additional free space loss.

On the contrary, lower frequencies offer advantages when the line of sight may be blocked because they can leverage diffraction to reach the intended receiver.

In the case of mesh networking, where the antenna should connect to several other nodes, it is better to use omnidirectional antennas.

The same type of polarization must be used at both ends of any radio link. For point-to-point links, parabolic antennas exist that may transmit/receive two different signals simultaneously at the same frequency but with orthogonal polarizations, thus permitting to increase the achievable throughput significantly and to improve the protection to multipath and to other transmission impairments.

4.2.2. Physical link length

4.2.2.1. Line-of-Sight

For short distance transmission, there is no strict requirement of line of sight between the transmitter and the receiver, and multipath can guarantee communication despite the existence of obstacles in the direct path.

For longer distances, the first requirement is the existence of an unobstructed line of sight between the transmitter and the receiver. For very long paths, the earth curvature is an obstacle that must be cleared, but the trajectory of the radio beam is not strictly a straight line due to the bending of the rays as a consequence of non-uniformities of the atmosphere. Most of the time this bending will mean that the radio horizon extends further than the optical horizon.

4.2.2.2. Transmitted and Received Power

Once a clear radio-electric line of sight is obtained, it is required that the received power is significantly above the sensitivity of the receiver, by what is known as the "link margin". The greater the link margin, the more reliable the link. For mission critical applications 20 dB margin is suggested, but for non critical ones 10 dB might suffice.

The sensitivity of the receiver decreases with the transmission speed, so more power is needed at greater transmission speeds.

Different options can be considered in order to achieve a given link margin (also called "fade margin"):

a) To increase the output power.The maximum transmitted power is specified by each country’s regulation, and for unlicensed frequencies is much lower than for licensed frequencies.

b) To increase the antenna gain. There is no limit in the gain of the receiving antenna, but high gain antennas are bulkier, present more wind resistance and require sturdy mounts to comply with tighter alignment requirements. The transmitter antenna gain is also regulated and can be different for point-to-point as for point-to-multipoint links.

c) To reduce the propagation loss, by using a more favorable frequency or a shorter path.

d) To use a more sensitive receiver. Receiver sensitivity can be improved by using better circuits, but it is ultimately limited by the thermal noise, which is proportional to temperature and bandwidth. One can increase the sensitivity by using a smaller receiving bandwidth, or by settling to lower throughput even in the same receiver bandwidth.

4.2.3. Media Access Control (MAC) Protocols for Wireless Links

Different protocols for Media Access Control, which also include physical layer (PHY) recommendations, are widely used in Alternative Network Deployments. Wireless standards ensure interoperability and usability to those who design, deploy and manage wireless networks.

The standards used in the vast majority of Alternative Networks come from the IEEE Standard Association’s IEEE 802 Working Group. Standards developed by other international entities can also be used, as e.g. the European Telecommunications Standards Institute (ETSI).

4.2.3.1. 802.11 (Wi-Fi)

The standard we are most interested in is 802.11 a/b/g/n/ac, as it defines the protocol for Wireless LAN. It is also known as "Wi-Fi". The original release (a/b) was issued in 1999 and allowed for rates up to 54 Mbit/s. The latest release (802.11ac) issued in 2011 reaches up to 866.7 Mbit/s. In 2012, the IEEE issued the 802.11-2012 Standard that consolidates all the previous amendments. The document is freely downloadable from IEEE Standards [IEEE].

4.2.3.1.1. Deployment planning for 802.11 wireless networks

To provide physical connectivity, wireless network devices must operate in the same part of the radio spectrum. This means that 802.11a radios will talk to 802.11a radios at around 5 GHz, and 802.11b/g radios will talk to other 802.11b/g radios at around 2.4 GHz. But an 802.11a device cannot interoperate with an 802.11b/g device, since they use completely different parts of the electromagnetic spectrum. More specifically, wireless interfaces must agree on a common channel. If one 802.11b radio card is set to channel 2 while another is set to channel 11, then the radios cannot communicate with each other.

Each 802.11 device can operate in one of four possible modes:

1. Master mode (also called AP or infrastructure mode) is used to create a service that looks like a traditional Access Point. Wireless interfaces in master mode can only communicate with interfaces that are associated with them in managed mode.

2. Managed mode is sometimes also referred to as client mode. Wireless interfaces in managed mode will join a network created by a master, and will automatically change their channel to match it. Managed mode interfaces do not communicate with each other directly, and only communicate with an associated master.

3. Ad-hoc mode creates a multipoint-to-multipoint network where there is no single master node or AP. In ad-hoc mode, each wireless interface communicates directly with its neighbors. Ad-hoc mode is often also called Mesh Networking.

4. Monitor mode is used by some tools (such as Kismet) to passively listen to all radio traffic on a given channel.

When implementing a point-to-point or point-to-multipoint link, one radio will typically operate in master mode, while the other(s) operate in managed mode. Ad-hoc is more flexible but has a number of performance issues as compared to using the master / managed modes.

4.2.3.1.2. Long Distances in 802.11

The MAC protocol in 802.11 is called CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) and was designed for short distances; the transmitter expects the reception of an acknowledgment for each transmitted unicast packet; if a certain waiting time is exceeded, the packet is retransmitted. This behavior makes necessary the adaptation of several MAC parameters when 802.11 is used in long links [Simo_b]. Even with this adaptation, the distance has a significant negative impact on the performance. For this reason, many vendors implement alternative medium access techniques that are offered alongside the standard CSMA/CA in their outdoor 802.11 products. These alternative proprietary MAC protocols usually employ some type of TDMA (Time Division Multiple Access). Low cost equipment using these techniques can offer high throughput at distances above 100 kilometers.

4.2.3.2. GSM

GSM (Global System for Mobile Communications), from ETSI, has also been used in Alternative Networks as Layer 2 option, as explained in [Mexican].

4.2.3.3. Dynamic Spectrum

Some Alternative Networks make use of TV White Spaces - a set of UHF and VHF television frequencies that can be utilized by secondary users in locations where it is unused by licensed primary users such as television broadcasters. Equipment that makes use of TV White Spaces is required to detect the presence of existing unused TV channels by means of a spectrum database and/or spectrum sensing in order to ensure that no harmful interference is caused to primary users. In order to smartly allocate interference-free channels to the devices, cognitive radios are used which are able to modify their frequency, power and modulation techniques to meet the strict operating conditions required for secondary users.

The use of the term "White Spaces" is often used to describe "TV White Spaces" as the VHF and UHF television frequencies were the first to be exploited on a secondary use basis. There are two dominant standards for TV white space communication: (i) the 802.11af standard [IEEE.802-11AF.2013] - an adaptation of the 802.11 standard for TV white space bands and (ii) the IEEE 802.22 standard [IEEE.802-22.2011] for long-range rural communication.

4.2.3.3.1. 802.11af

802.11af [IEEE.802-11AF.2013] is a modified version of the 802.11 standard operating in TV White Space bands using Cognitive Radios to avoid interference with primary users. The standard is often referred to as White-Fi or "Super Wi-Fi" and was approved in February 2014. 802.11af contains much of the advances of all the 802.11 standards including recent advances in 802.11ac such as up to four bonded channels, four spatial streams and very high rate 256-QAM modulation but with improved in-building penetration and outdoor coverage. The maximum data rate achievable is 426.7 Mbps for countries with 6/7 MHz channels and 568.9 Mbps for countries with 8

MHz channels. Coverage is typically limited to 1km although longer range at lower throughput and using high gain antennas will be possible.

Devices are designated as enabling stations (Access Points) or dependent stations (clients). Enabling stations are authorized to control the operation of a dependent station and securely access a geolocation database. Once the enabling station has received a list of available white space channels it can announce a chosen channel to the dependent stations for them to communicate with the enabling station. 802.11af also makes use of a registered location server - a local database that organizes the geographic location and operating parameters of all enabling stations.

4.2.3.3.2. 802.22

802.22 [IEEE.802-22.2011] is a standard developed specifically for long range rural communications in TV white space frequencies and first approved in July 2011. The standard is similar to the 802.16 (WiMax) [IEEE.802-16.2008] standard with an added cognitive radio ability. The maximum throughput of 802.22 is 22.6 Mbps for a single 8 MHz channel using 64-QAM modulation. The achievable range using the default MAC scheme is 30 km, however 100 km is possible with special scheduling techniques. The MAC of 802.22 is specifically customized for long distances - for example, slots in a frame destined for more distant Consumer Premises Equipment (CPEs) are sent before slots destined for nearby CPEs.

Base stations are required to have a Global Positioning System (GPS) and a connection to the Internet in order to query a geolocation spectrum database. Once the base station receives the allowed TV channels, it communicates a preferred operating white space TV channel with the CPE devices. The standard also includes a co-existence mechanism that uses beacons to make other 802.22 base stations aware of the presence of a base station that is not part of the same network.

5. Upper layers

5.1. Layer 3

5.1.1. IP addressing

Most known Alternative Networks started in or around the year 2000. IPv6 was fully specified by then, but almost all Alternative Networks still use IPv4. A survey [Avonts] indicated that IPv6 rollout presents a challenge to Community Networks.

Most Community Networks use private IPv4 address ranges, as defined by [RFC1918]. The motivation for this was the lower cost and the simplified IP allocation because of the large available address ranges.

5.1.2. Routing protocols

As stated in previous sections, Alternative Networks are composed of possibly different layer 2 devices, resulting in a mesh of nodes. Connection between different nodes is not guaranteed and the link stability can vary strongly over time. To tackle this, some Alternative Networks use mesh network routing protocols while other networks use more traditional routing protocols. Some networks operate multiple routing protocols in parallel. For example, they use a mesh protocol inside different islands and use traditional routing protocols to connect these islands.

5.1.2.1. Traditional routing protocols

The Border Gateway Protocol (BGP), as defined by [RFC4271] is used by a number of Community Networks, because of its well-studied behavior and scalability.

For similar reasons, smaller networks opt to run the Open Shortest Path First (OSPF) protocol, as defined by [RFC2328].

5.1.2.2. Mesh routing protocols

A large number of Alternative Networks use the Optimized Link State Routing Protocol (OLSR) routing protocol as defined in [RFC3626]. The pro-active link state routing protocol is a good match with Alternative Networks because it has good performance in mesh networks where nodes have multiple interfaces.

The Better Approach To Mobile Adhoc Networking (BATMAN) [Abolhasan] protocol was developed by members of the Freifunk community. The protocol handles all routing at layer 2, creating one bridged network.

Parallel to BGP, some networks also run the BatMan-eXperimental (BMX6) protocol [Neumann]. This is an advanced version of the BATMAN protocol which is based on IPv6 and tries to exploit the social structure of Alternative Networks.

5.2. Transport layer

5.2.1. Traffic Management when sharing network resources

When network resources are shared, a special care has to be put on the management of the traffic at upper layers. From a crowdshared perspective, and considering just regular TCP connections during the critical sharing time, the Access Point offering the service is likely to be the bottleneck of the connection. This is the main concern of sharers, having several implications. There should be an adequate Active Queue Management (AQM) mechanism that implements a Lower-than-best-effort (LBE) [RFC6297] policy for the user and protects the sharer. Achieving LBE behavior requires the appropriate tuning of the well known mechanisms such as Explicit Congestion Notification (ECN) [RFC3168], or Random Early Detection (RED) [RFC2309], or other more recent AQM mechanisms such as Controlled Delay (CoDel) and [I-D.ietf-aqm-codel] PIE (Proportional Integral controller Enhanced) [I-D.ietf-aqm-pie] that aid on keeping low latency.

However, other bottlenecks besides client’s access bottleneck may not be controlled by the previously mentioned protocols. Therefore, recently proposed transport protocols like LEDBAT [Ros], [Komnios] with the purpose of transporting scavenger traffic may be a solution. LEDBAT requires the cooperation of both the client and the server to achieve certain target delay, therefore controlling the impact of the user along all the path.

There are applications that manage aspects of the network from the sharer side and from the client side. From sharer’s side, there are applications to centralize the management of the APs conforming the network that have been recently proposed by means of SDN [Sathiaseelan_a], [Suresh]. There are also other proposals such as Wi2Me [Lampropulos] that manage the connection to several Community Networks from the client’s side. These applications have shown to improve the client performance compared to a single-Community Network client.

5.2.2. Multi-hop issues

On the other hand, transport protocols inside a multiple hop wireless mesh network are likely to suffer performance degradation for multiple reasons, e.g., hidden terminal problem, unnecessary delays on the TCP ACK clocking that decrease the throughout or route changing [Hanbali]. There are some options for network configuration. The implementation of an easy-to-adopt solution for TCP over mesh networks may be implemented from two different perspectives. One way is to use a TCP-proxy to transparently deal with the different impairments ([RFC3135]). Another way is to adopt end-to-end solutions for monitoring the connection delay so that the receiver adapts the TCP reception window (rwnd) [Castignani_c]. Similarly, the ACK Congestion Control (ACKCC) mechanism [RFC5690] could deal with TCP-ACK clocking impairments due to inappropriate delay on ACK packets. ACKCC compensates in an end-to-end fashion the throughput degradation due to the effect of media contention as well as the unfairness experienced by multiple uplink TCP flows in a congested Wi-Fi access.

5.3. Services provided

This section provides an overview of the services between hosts inside the network. They can be divided into Intranet services, connecting hosts between them, and Internet services, connecting to nodes outside the network.

5.3.1. Intranet services

Intranet services can include, but are not limited to:

- VoIP (e.g. with SIP)

- Remote desktop (e.g. using my home computer and my Internet connection when I am on holidays in a village).

- FTP file sharing (e.g. distribution of Linux software).

- P2P file sharing.

- Public video cameras.

- DNS.

- Online games servers.

- Jabber instant messaging.

- IRC chat.

- Weather stations.

- NTP.

- Network monitoring.

- Videoconferencing / streaming.

- Radio streaming.

5.3.2. Access to the Internet

5.3.2.1. Web browsing proxies

A number of federated proxies may provide web browsing service for the users. Other services (file sharing, skype, etc.) are not usually allowed in many Alternative Networks due to bandwidth limitations.

5.3.2.2. Use of VPNs

Some "micro-ISPs" may use the network as a backhaul for providing Internet access, setting up VPNs from the client to a machine with Internet access.

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8. IANA Considerations

This memo includes no request to IANA.

9. Security Considerations

No security issues have been identified for this document.

10. References

10.1. Normative References

[IEEE] Institute of Electrical and Electronics Engineers, IEEE, "IEEE Standards association", 2012.

[IEEE.802-11AF.2013] "Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications - Amendment 5: Television White Spaces (TVWS) Operation", IEEE Standard 802.11af, Oct 2009, <http://standards.ieee.org/getieee802/download/802.11af-2013.pdf>.

[IEEE.802-16.2008] "Information technology - Telecommunications and information exchange between systems - Broadband wireless metropolitan area networks (MANs) - IEEE Standard for Air Interface for Broadband Wireless Access Systems", IEEE Standard 802.16, Jun 2008, <http://standards.ieee.org/getieee802/download/802.16-2012.pdf>.

[IEEE.802-22.2011] "Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Policies and procedures for operation in the TV Bands", IEEE Standard 802.22, Jul 2011, <http://standards.ieee.org/getieee802/download/802.11af-2013.pdf>.

[RFC1918] Rekhter, Y., Moskowitz, R., Karrenberg, D., Groot, G., and E. Lear, "Address Allocation for Private Internets", BCP 5, RFC 1918, February 1996.

[RFC2309] Braden, B., Clark, D., Crowcroft, J., Davie, B., Deering, S., Estrin, D., Floyd, S., Jacobson, V., Minshall, G., Partridge, C., Peterson, L., Ramakrishnan, K., Shenker, S., Wroclawski, J., and L. Zhang, "Recommendations on Queue Management and Congestion Avoidance in the Internet", RFC 2309, April 1998.

[RFC2328] Moy, J., "OSPF Version 2", STD 54, RFC 2328, April 1998.

[RFC3135] Border, J., Kojo, M., Griner, J., Montenegro, G., and Z. Shelby, "Performance Enhancing Proxies Intended to Mitigate Link-Related Degradations", RFC 3135, June 2001.

[RFC3168] Ramakrishnan, K., Floyd, S., and D. Black, "The Addition of Explicit Congestion Notification (ECN) to IP", RFC 3168, September 2001.

[RFC3626] Clausen, T. and P. Jacquet, "Optimized Link State Routing Protocol (OLSR)", RFC 3626, October 2003.

[RFC4271] Rekhter, Y., Li, T., and S. Hares, "A Border Gateway Protocol 4 (BGP-4)", RFC 4271, January 2006.

[RFC5690] Floyd, S., Arcia, A., Ros, D., and J. Iyengar, "Adding Acknowledgement Congestion Control to TCP", RFC 5690, February 2010.

[RFC6297] Welzl, M. and D. Ros, "A Survey of Lower-than-Best-Effort Transport Protocols", RFC 6297, June 2011.

10.2. Informative References

[Abolhasan]
Abolhasan, M., Hagelstein, B., and J. Wang, "Real-world performance of current proactive multi-hop mesh protocols", In Communications, 2009. APCC 2009. 15th Asia-Pacific Conference on (pp. 44-47). IEEE. , 2009.

[Airjaldi]
Rural Broadband (RBB) Pvt. Ltd., Airjaldi., "Airjaldi service", Airjaldi web page, www.airjaldi.net , 2015.

[Avonts] Avonts, J., Braem, B., and C. Blondia, "A Questionnaire based Examination of Community Networks", Proceedings Wireless and Mobile Computing, Networking and Communications (WiMob), 2013 IEEE 8th International Conference on (pp. 8-15) , 2013.

[Bernardi]
Bernardi, B., Buneman, P., and M. Marina, "Tegola tiered mesh network testbed in rural Scotland", Proceedings of the 2008 ACM workshop on Wireless networks and systems for developing regions (WiNS-DR ’08). ACM, New York, NY, USA, 9-16 , 2008.

[Braem] Braem, B., Baig Vinas, R., Kaplan, A., Neumann, A., Vilata i Balaguer, I., Tatum, B., Matson, M., Blondia, C., Barz, C., Rogge, H., Freitag, F., Navarro, L., Bonicioli, J., Papathanasiou, S., and P. Escrich, "A case for research with and on community networks", ACM SIGCOMM Computer Communication Review vol. 43, no. 3, pp. 68-73, 2013.

[Castignani_a]
Castignani, G., Loiseau, L., and N. Montavont, "An Evaluation of IEEE 802.11 Community Networks Deployments", Information Networking (ICOIN), 2011 International Conference on , vol., no., pp.498,503, 26-28 , 2011.

[Castignani_b]
Castignani, G., Monetti, J., Montavont, N., Arcia-Moret, A., Frank, R., and T. Engel, "A Study of Urban IEEE 802.11 Hotspot Networks: Towards a Community Access Network", Wireless Days (WD), 2013 IFIP , pp.1,8, 13-15 , 2013.

[Castignani_c]
Castignani, G., Arcia-Moret, A., and N. Montavont, "A study of the discovery process in 802.11 networks", SIGMOBILE Mob. Comput. Commun. Rev., vol. 15, no. 1, p. 25 , 2011.

[Cerda-Alabern]
Cerda-Alabern, L., "On the topology characterization of Guifi.net", Proceedings Wireless and Mobile Computing, Networking and Communications (WiMob), 2012 IEEE 8th International Conference on (pp. 389-396) , 2012.

[DAE] European Commission, EC., "A Digital Agenda for Europe", Communication from the Commission of 19 May 2010 to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A Digital Agenda for Europe , 2010.

[Everylayer]
former Volo Broadband, Everylayer., "Everylayer", Everylayer web page, http://www.everylayer.com/ , 2015.

[Flickenger]
Flickenger, R., Okay, S., Pietrosemoli, E., Zennaro, M., and C. Fonda, "Very Long Distance Wi-Fi Networks", NSDR 2008, The Second ACM SIGCOMM Workshop on Networked Systems for Developing Regions. USA, 2008 , 2008.

[FNF] The Free Network Foundation, FNF., "The Free Network Foundation", The Free Network Foundation web page, https://thefnf.org/ , 2014.

[Fon] Fon Wireless Limited, Fon., "What is Fon", Fon web page, https://corp.fon.com/en , 2014.

[Hanbali] Hanbali, A., Altman, E., and P. Nain, "A Survey of TCP over Ad Hoc Networks", IEEE Commun. Surv. Tutorials, vol. 7, pp. 22-36 , 2005.

[Heer] Heer, T., Hummen, R., Viol, N., Wirtz, H., Gotz, S., and K. Wehrle, "Collaborative municipal Wi-Fi networks-challenges and opportunities", Pervasive Computing and Communications Workshops (PERCOM Workshops), 2010 8th IEEE International Conference on (pp. 588-593). IEEE. , 2010.

[I-D.ietf-aqm-codel]
Nichols, K., Jacobson, V., McGregor, A., and J. Jana, "Controlled Delay Active Queue Management", draft-ietf-aqm-codel-01 (work in progress), April 2015.

[I-D.ietf-aqm-pie]
Pan, R., Natarajan, P., Baker, F., and G. White, "PIE: A Lightweight Control Scheme To Address the Bufferbloat Problem", draft-ietf-aqm-pie-01 (work in progress), March 2015.

[Komnios] Komnios, I., Sathiaseelan, A., and J. Crowcroft, "LEDBAT performance in subpacket regimes", IEEE/IFIP WONS, Austria, April 2014 , 2014.

[Lampropulos]
Lampropulos, A., Castignani, G., Blanc, A., and N. Montavont, "Wi2Me: A Mobile Sensing Platform for Wireless Heterogeneous Networks", 32nd International Conference on Distributed Computing Systems Workshops (ICDCS Workshops), 2012, pp. 108-113 , 2012.

[Lowenstedt]
Huggler, J., "Lowenstedt Villagers Built Own Fiber Optic Network", The Telegraph, 03 Jun 2014, available at http://www.telegraph.co.uk/news/worldnews/europe/germany/10871150/German-villagers-set-up-their-own-broadband-network.html , 2014.

[Mexican] Varma, S., "Lowenstedt Villagers Built Own Fiber Optic Network", The Times of India, 27 Aug 2013, available at http://timesofindia.indiatimes.com/world/rest-of-world/Ignored-by-big-companies-Mexican-village-creates-its-own-mobile-service/articleshow/22094736.cms , 2013.

[Neumann] Neumann, A., Lopez, E., and L. Navarro, "An evaluation of bmx6 for community wireless networks", In Wireless and Mobile Computing, Networking and Communications (WiMob), 2012 IEEE 8th International Conference on (pp. 651-658). IEEE. , 2012.

[PAWS] Sathiaseelan, A., Crowcroft, J., Goulden, M., Greiffenhagen, C., Mortier, R., Fairhurst, G., and D. McAuley, "Public Access WiFi Service (PAWS)", Digital Economy All Hands Meeting, Aberdeen , Oct 2012.

[Pietrosemoli]
Pietrosemoli, E., Zennaro, M., and C. Fonda, "Low cost carrier independent telecommunications infrastructure", In proc. 4th Global Information Infrastructure and Networking Symposium, Choroni, Venezuela , 2012.

[Rendon] Rendon, A., Ludena, P., and A. Martinez Fernandez, "Tecnologias de la Informacion y las Comunicaciones para zonas rurales Aplicacion a la atencion de salud en paises en desarrollo", CYTED. Programa Iberoamericano de Ciencia y Tecnologia para el Desarrollo , 2011.

[Rey] Rey-Moreno, C., Bebea-Gonzalez, I., Foche-Perez, I., Quispe-Taca, R., Linan-Benitez, L., and J. Simo-Reigadas, "A telemedicine WiFi network optimized for long distances in the Amazonian jungle of Peru.", Proceedings of the 3rd Extreme Conference on Communication: The Amazon Expedition, ExtremeCom ’11 ACM, 2011.

[Ros] Ros, D. and M. Welzl, "Assessing LEDBAT’s Delay Impact", Communications Letters, IEEE , vol.17, no.5, pp.1044,1047, May 2013 , 2013.

[Samanta] Samanta, V., Knowles, C., Wagmister, J., and D. Estrin, "Metropolitan Wi-Fi Research Network at the Los Angeles State Historic Park", The Journal of Community Informatics, North America, 4 , May 2008.

[Sathiaseelan_a] Sathiaseelan, A., Rotsos, C., Sriram, C., Trossen, D., Papadimitriou, P., and J. Crowcroft, "Virtual Public Networks", In Software Defined Networks (EWSDN), 2013 Second European Workshop on (pp. 1-6). IEEE. , 2013.

[Sathiaseelan_b] Sathiaseelan, A. and J. Crowcroft, "LCD-Net: Lowest Cost Denominator Networking", ACM SIGCOMM Computer Communication Review , Apr 2013.

[Sathiaseelan_c] Sathiaseelan, A., Mortier, R., Goulden, M., Greiffenhagen, C., Radenkovic, M., Crowcroft, J., and D. McAuley, "A Feasibility Study of an In-the-Wild Experimental Public Access WiFi Network", ACM DEV 5, Proceedings of the Fifth ACM Symposium on Computing for Development, San Jose , Dec 2014 pp 33-42, 2014.

[Simo_a] Simo-Reigadas, J., Morgado, E., Municio, E., Prieto-Egido, I., and A. Martinez-Fernandez, "Assessing IEEE 802.11 and IEEE 802.16 as backhaul technologies for rural 3G femtocells in rural areas of developing countries", EUCNC 2014 , 2014.

[Simo_b] Simo-Reigadas, J., Martinez-Fernandez, A., Ramos-Lopez, J., and J. Seoane-Pascual, "Modeling and Optimizing IEEE 802.11 DCF for Long-Distance Links", IEEE TRANSACTIONS ON MOBILE COMPUTING, 9(6), pp. 881-896 , 2010.

[Suresh] Suresh, L., Schulz-Zander, J., Merz, R., Feldmann, A., and T. Vazao, "Towards Programmable Enterprise WLANs with ODIN", In Proceedings of the first workshop on Hot topics in software defined networks (HotSDN ’12). ACM, New York, NY, USA, 115-120 , 2012.

[Vega] Vega, D., Cerda-Alabern, L., Navarro, L., and R. Meseguer, "Topology patterns of a community network: Guifi. net.", Proceedings Wireless and Mobile Computing, Networking and Communications (WiMob), 2012 IEEE 8th International Conference on (pp. 612-619) , 2012.

[WiLD] Patra, R., Nedevschi, S., Surana, S., Sheth, A., Subramanian, L., and E. Brewer, "WiLDNet: Design and Implementation of High Performance WiFi Based Long Distance Networks", NSDI (Vol. 1, No. 1, p. 1) , Apr 2007.

[WNDW] Wireless Networking in the Developing World/Core Contributors, "Wireless Networking in the Developing World, 3rd Edition", The WNDW Project, available at wndw.net , 2013.

[WSIS] International Telecommunications Union, ITU, "Declaration of Principles. Building the Information Society: A global challenge in the new millenium", World Summit on the Information Society, 2003, at http://www.itu.int/wsis, accessed 12 January 2004. , Dec 2013.

[Zennaro] Zennaro, M., Fonda, C., Pietrosemoli, E., Muyepa, A., Okay, S., Flickenger, R., and S. Radicella, "On a long wireless link for rural telemedicine in Malawi", 6th International Conference on Open Access, Lilongwe, Malawi , Nov 2008.

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