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# Alternative Network Deployments: Taxonomy, characterization, technologies and architectures
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## Abstract

This document presents a taxonomy of a set of "Alternative Network Deployments" emerged in the last decade with the aim of bringing Internet connectivity to people. They employ architectures and topologies different from those of mainstream networks, and rely on alternative business models.

The document also surveys the technologies deployed in these networks, and their differing architectural characteristics, including a set of definitions and shared properties.

The classification considers models such as Community Networks, 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 networks that provide connectivity by sharing wireless resources of the users.

## Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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## Table of Contents

## 1. Introduction

One of the aims of the Global Access to the Internet for All (GAIA) IRTF research group is "to document and share deployment experiences and research results to the wider community through scholarly publications, white papers, Informational and Experimental RFCs, etc." [GAIA]. In line with this objective, this document proposes a classification of "Alternative Network Deployments". This term includes a set of network access models that have emerged in the last decade with the aim of providing Internet connection, following topological, architectural and business models that differ from the so-called "mainstream" ones, where a company deploys the infrastructure connecting the users, who pay a subscription fee to be connected and make use of it.

Several initiatives throughout the world have built these large scale networks, using predominantly wireless technologies (including long distance) due to the reduced cost of using unlicensed spectrum. Wired technologies such as fiber are also used in some of these networks.

The classification considers several types of alternate deployments: Community Networks are self-organized networks wholly owned by the community; networks acting 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 has been motivated by a variety of factors such as the lack of wired and cellular infrastructures in rural/remote areas [Pietrosemoli]. In some cases, alternative networks may provide more localized communication services as well as Internet backhaul support through peering agreements with mainstream network operators. In other cases, they are built as a complement or an alternative to commercial Internet access provided by mainstream network operators.

The present document is intended to provide a broad overview of initiatives, technologies and approaches employed in these networks, including some real examples. References describing each kind of network are also provided.

### 1.1. Mainstream networks

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

- Regarding scale, they are usually large networks spanning entire regions.
- Top-down control of the network and centralized approach.
- They require a substantial investment in infrastructure.
- Users in mainstream networks do not participate in the network design, deployment, operation and maintenance.

### 1.2. Alternative Networks

The term "Alternative Network" proposed in this document refers to the networks that do not share the characteristics of "mainstream network deployments".

## 2. Terms used in this document

This document follows a multidisciplinary approach, considering the multidisciplinary nature of the Internet and the problems being addressed. Therefore, some concepts used in fields and disciplines different from networking are being used. This subsection summarizes these terms, and the meaning being attributed to them.

- "Global north" and "global south": Although there is no consensus on the terms to be used when talking about the different development level of countries, we will employ the term "global south" to refer to nations with a relatively lower standard of living. This distinction is normally intended to reflect basic economic country conditions. In common practice, Japan in Asia, Canada and the United States in northern America, Australia and New Zealand in Oceania, and Europe are considered "developed" regions or areas [UN], so we will employ the term "global north" when talking about them.

- The "Digital Divide". The following dimensions are considered to be meaningful when measuring the digital development state of a country: infrastructures (availability and affordability), Information and Communications Technology (ICT) sector (human capital and technological industry), digital literacy, legal and regulatory framework and, content and services. A lack of digital development in one or more of these dimensions is what has been referred as the "Digital Divide" [Norris].

- Rural zone. The document will follow the definition of "rural " proposed by G. P. Wibberley in 1972 [Wibberley]: "The word describes those parts of a country which show unmistakable signs of being dominated by extensive uses of land, either at the present time or in the immediate past. It is important to emphasise that these extensive uses might have had a domination over an area which has now gone because this allows us to look at settlements which to the eye still appear to be rural but which, in practice, are merely an extension of the city resulting from the development of the commuter train and the private motor car" [Clot].

- Urban zone. The definition of "urban" does vary between countries, as shown in [UNStats]. For example, in the United States they are defined as "Agglomerations of 2 500 or more inhabitants, generally having population densities of 1 000 persons per square mile or more." In China the term "city" is proper of those designated by the State Council. In Liberia they are "Localities of 2 000 or more inhabitants." In France they are "communes containing an agglomeration of more than 2 000 inhabitants living in contiguous houses or with not more than 200 metres between houses." In Guam, they are "agglomerations of 2 500 or more inhabitants, generally having population densities of 1 000 persons per square mile or more, referred to as "urban clusters"".

- Demand: In economics, it describes a consumer’s desire and willingness to pay a price for a specific good or service.

- Provision is the act of making an asset available for sale. In this document we will mainly use it as the act of making a network service available to the inhabitants of a zone.

- Underserved area. Area in which the market permanently fails to provide the information and communications services demanded by the population.

- "Free Networks" (also called "Network Commons") [FNF]. A definition of Free Network is proposed by the Free Network Foundation (see https://thefnf.org) as the one that "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 https://guifi.net/en/FONNC) 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."

## 3. Scenarios where Alternative Networks are deployed

Different studies have reported that as much as 60% of the people on the planet do not have Internet connectivity [Sprague], [InternetStats]. In addition, those unconnected are unevenly

distributed: only 31 percent of the population in "global south" countries had access in 2014, against 80 percent in "global north" countries [WorldBank2016]. This is one of the reasons behind the inclusion of the objective of providing "significantly increase access to ICT and strive to provide universal and affordable access to internet in LDCs by 2020," as one of the targets in the Sustainable Development Goals (SDGs) [SDG], considered as a part of "Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation."

For the purpose of this document, a distinction between "global north" and "global south" zones is made, highlighting the factors related to ICT (Information and Communication Technologies), which can be quantified in terms of:

- The availability of both national and international bandwidth, as well as equipment.
- The difficulty to pay for the services and the devices required to access the ICTs.
- The instability and or lack of power supply.
- The scarcity of qualified staff.
- The existence of a policy and regulatory framework that hinders the development of these models in favor of state monopolies or incumbents.

In this context, the World Summit of the Information Society aimed at achieving "a people-centred, inclusive and development-oriented Information Society, where everyone can create, access, utilize and share information and knowledge. Therefore, enabling individuals, communities and people to achieve their full potential in promoting their sustainable development and improving their quality of life". It also called upon "governments, private sector, civil society and international organizations" to actively engage to work towards the bridging of the digital divide [WSIS].

Some Alternative Networks have been deployed in underserved areas, where citizens may be compelled to take a more active part in the design and implementation of ICT solutions. However, Alternative Networks are also present in some "global north" countries, being built as an alternative to commercial ones managed by mainstream network operators.

The consolidation of a number of mature Alternative Networks (e.g. Community Networks) sets a precedent for civil society members 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 content and services targeting the locality of each network.

### 3.1. Urban vs. Rural Areas

The differences presented in the previous section are not only present between countries, but within them too. This is especially the case for rural inhabitants, who represent approximately 55% of the world's population [IFAD2011], 78% of them in "global south" countries [ITU2011]. According to the World Bank, adoption gaps "between rural and urban populations are falling for mobile phones but increasing for the internet" [WorldBank2016].

Although it is impossible to generalize among them, there exist some common features in rural areas that have prevented incumbent operators for providing access and that, at the same time, challenge the deployment of alternative infrastructures [Brewer], [Nungu], [Simo_c].

These challenges include:

- Low per capita income, as the local economy is mainly based on subsistence agriculture, farming and fishing.
- Scarcity or absence of basic infrastructure, such as electricity, water and access roads.
- Low population density and distance (spatial or affective) between population clusters.
- Underdeveloped social services, such as healthcare and education.
- Lack of adequately educated and trained technicians, and high potential for those trained to migrate due to lack of opportunities and low salaries in rural areas, or to start their own companies [McMahon].
- High cost of Internet access [Mathee].
- Harsh environments leading to failure in electronic communication devices [Johnson].

However, the proliferation of urban Community Networks, where scarcity of spectrum, scale, and heterogeneity of devices pose certain challenges to their stability and the services they aim to

provide, has fuelled the creation of low-cost, low-consumption, low-complexity off-the-shelf wireless devices. These devices can simplify the deployment and maintenance of alternative infrastructures in rural areas.

### 3.2. 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 tends to fit a power law distribution. Moreover, these networks are 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 growth 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 conveys the Internet connection to relevant organizations 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 to the network. Other proposals like Virtual Public Networks [Sathiaseelan_a] can also extend the service.

## 4. Classification criteria

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

### 4.1. Commercial model / promoter

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

- A community of users.
- A public stakeholder.
- A private company.
- Supporters of a crowdshared approach.

- A community that already owns some infrastructure shares it with an operator, which uses it for backhauling purposes.
- A research or academic entity.

### 4.2. Goals and motivation

Alternative Networks can also be classified according to the underlying motivation for them, e.g., 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.

### 4.3. Administrative model

- Centralized, where a single authority (e.g. a company, a public stakeholder) plans and manages the network.
- Non-centralized, i.e. the network is managed following a distributed approach, in which a whole community may participate. The network may also grow according to the fact of new users joining it, but not following a plan.

### 4.4. Technologies employed

- Standard Wi-Fi. Many Alternative Networks are based on the standard IEEE 802.11 [IEEE.802-11-2012] using the Distributed Coordination Function.
- Wi-Fi modified for long distances (WiLD), either with CSMA/CA or with an alternative TDMA MAC [Simo_b].

- o 802.16-compliant (WiMax) [IEEE.802-16.2008] systems over non-licensed bands.

- o Dynamic Spectrum Solutions (e.g. based on the use of white spaces), a set of television frequencies that can be utilized by secondary users in locations where they are unused, e.g., IEEE 802.11af [IEEE.802-11AF.2013] or 802.22 [IEEE.802-22.2011].

- o Satellite solutions can also be employed to give coverage to wide areas.

- o Low-cost optical fiber systems are used to connect households in some villages.

### 4.5. Typical scenarios

The scenarios where Alternative Networks are usually deployed can be classified as:

- o Urban / Rural areas.

- o "Global north" / "Global south" countries.

## 5. Classification of Alternative Networks

This section classifies Alternative Networks according to the criteria explained previously. Each of them has different incentive structures, maybe common technological challenges, but most importantly interesting usage challenges which feed 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 "Classification criteria" subsection.

In some cases, real examples of Alternative Networks are cited.

### 5.1. Community Networks

| Commercial model/promoter | community |
|---|---|
| Goals and motivation | reducing hurdles; to serve underserved areas; network neutrality |
| Administration | non-centralized |
| Technologies | Wi-Fi [IEEE.802-11-2012], optical fiber |
| Typical scenarios | urban and rural |

Table 1: Community Networks' characteristics summary

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

- They start and grow organically, they are open to participation from everyone, sharing an open peering agreement. Community members directly contribute active (not just passive) network infrastructure. The network grows as new hosts and links are added.

- Knowledge about building and maintaining the network and ownership of the network itself is non-centralized and open. There is a shared platform (e.g. a web site) where a minimum coordination is performed. This way, community members with the right permissions have an obvious and direct form of organizational control over the overall operation of the network (e.g. IP addresses, routing, etc.) 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 minimal 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, profit can only be made by offering services and not simply by supplying the infrastructure, because the infrastructure is neutral, free, and open (mainstream Internet Service Providers base their business on the control of the infrastructure). In Community Networks, everybody keeps the ownership of what he/she has contributed.

The majority of Community Networks comply with the definition of Free Network, included in Section 2.

## 5.2. Wireless Internet Service Providers, WISPs

| | |
|---|---|
| Commercial model/promoter | company |
| Goals and motivation | to serve underserved areas; to reduce capital expenditures in Internet access; to provide additional sources of capital |
| Administration | centralized |
| Technologies | wireless e.g. [IEEE.802-11-2012], [IEEE.802-16.2008], 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 mainstream telcos or ISPs. WISPs mostly use wireless point-to-multipoint links using unlicensed spectrum but often must resort to licensed frequencies. Use of licensed frequencies is common in regions where unlicensed spectrum is either perceived to be crowded, or too unreliable to offer commercial services, or where unlicensed spectrum faces 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 hardware from companies such as 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.

## 5.3. Shared infrastructure model

| Commercial model/promoter | shared: companies and users |
|---|---|
| Goals and motivation | to eliminate a capital expenditures barrier (to operators); lower the operating expenses (supported by the community); to extend coverage to underserved areas |
| Administration | Non-centralized |
| Technologies | wireless in non-licensed bands, [WiLD] and/or low-cost fiber, mobile femtocells |
| Typical scenarios | rural areas, and more particularly rural areas in "global south" regions |

Table 3: Shared infrastructure characteristics summary

In conventional networks, the operator usually owns the telecommunications infrastructure required for the service, or sometimes rents infrastructure to/from 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 on investment.

When users already own deployed infrastructure, either individually or as a community, sharing that infrastructure with an operator can benefit both parties and is a solution that has been deployed in some areas. For the operator, this provides a significant reduction in the initial investment needed to provide services in small rural localities because capital expenditure is only associated with the access network. Renting capacity in the users' network for backhauling only requires an increment in the operating expenditure. This approach also benefits the users in two ways: they obtain improved access to telecommunications services that would not be accessible otherwise, and they can derive some income from the operator that helps to offset the network's operating costs, 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 (small, low-power cellular base stations), 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 excess capacity, 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 backhaul 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 TUCAN3G project, (see http://www.ict-tucan3g.eu/) which deployed demonstrator networks in two regions in the Amazon forest in Peru. In these networks [Simo_a], the operator and several rural communities cooperated to provide services through rural networks built up with WiLD links [WiLD]. In these cases, the networks belong to the public health authorities and were deployed with funds come from international cooperation for telemedicine purposes. Publications that justify the feasibility of this approach can also be found on that website.

### 5.4. Crowdshared approaches, led by the users and third party stakeholders

| | |
|---|---|
| Commercial model/promoter | community, public stakeholders, private companies, supporters of a crowdshared approach |
| Goals and motivation | sharing connectivity and resources |
| Administration | Non-centralized |
| Technologies | Wi-Fi [IEEE.802-11-2012] |
| 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 examples are found in the networks created and managed by City Councils (e.g., [Heer]). The "openwireless movement" (https://openwireless.org/) also promotes the sharing of private wireless networks.

In the same way, some companies [Fon] promote the use of Wi-Fi routers with 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 with the community. Some users can even get some revenue every time another user connects to their Wi-Fi access point. Users that are not part of the community can buy passes in order to use the network. Some mainstream telecommunications operators collaborate with these communities, by including the functionality required to create the two access networks in their routers. Some of these efforts are surveyed in [Shi]

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 in a specific location, at 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 network capacity 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 registration, 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 not an Application Service Provider (ASP) either since it does not provide user services. Virtual Operators may also be stakeholders with socio-environmental objectives. They can be local governments, grass-roots 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 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.

### 5.5. Testbeds for research purposes

| | |
|---|---|
| Commercial model/promoter | research / academic entity |
| Goals and motivation | research |
| Administration | centralized initially, but it may end up in a non-centralized 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 non-centralized model in which other local stakeholders assume part of the network administration [Rey].

## 6. Technologies employed

### 6.1. Wired

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

### 6.2. Wireless

The vast majority of Alternative Network Deployments are based on different wireless technologies [WNDW]. Below we summarize the options and trends when using these features in Alternative Networks.

#### 6.2.1. 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).

##### 6.2.1.1. 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) approved in 2013 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].

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, distance has a significant negative impact on 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.

##### 6.2.1.2. GSM

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

##### 6.2.1.3. 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 they are 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.

#### 6.2.1.3.1. 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 1 km 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.

#### 6.2.1.3.2. 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.

# 7. Upper layers

## 7.1. Layer 3

### 7.1.1. 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.

### 7.1.2. 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 may use a mesh protocol inside different islands and rely on traditional routing protocols to connect these islands.

#### 7.1.2.1. 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].

#### 7.1.2.2. Mesh routing protocols

A large number of Alternative Networks use the Optimized Link State Routing Protocol (OLSR) 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.

### 7.2. Transport layer

#### 7.2.1. Traffic Management when sharing network resources

When network resources are shared (as e.g. in the networks explained in Section 5.4), special care has to be taken with 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 low latency.

### 7.3. 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.

#### 7.3.1. 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 away).
- FTP file sharing (e.g. distribution of software and media).
- P2P file sharing.
- Public video cameras.
- DNS.
- Online games servers.
- Jabber instant messaging.
- IRC chat.
- Weather stations.
- NTP.
- Network monitoring.
- Videoconferencing / streaming.
- Radio streaming.
- Message / Bulletin board.

#### 7.3.2. Access to the Internet

#### 7.3.2.1. Web browsing proxies

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

#### 7.3.2.2. 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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## 10. IANA Considerations

This memo includes no request to IANA.

## 11. Security Considerations

No security issues have been identified for this document.

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