Wireless Networking in the Developing World

Second Edition

A practical guide to planning and building low-cost telecommunications infrastructure

Wireless Networking in the Developing World

For more information about this project, visit us online at *http://wndw.net/*

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About This Book

This book is part of a set of related materials about the same topic: Wireless Networking in the Developing World. The WNDW project includes:

- Printed books, available on demand

- Several translations, including French, Spanish, Portuguese, Italian, Arabic, and others

- A DRM-free PDF and HTML version of the book

- An archived mailing list for discussion of the concepts and techniques described in the book

- Additional case studies, training course material, and related information

For all of this material and more, see our website at *http://wndw.net/*

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The website will include additional case studies, currently available equipment, and more external website references. Volunteers and ideas are welcome. Please join the mailing list and send ideas.

The training course material was written for courses given by the Association for Progressive Communications and the Abdus Salam International Center for Theoretical Physics. See *http://www.apc.org/wireless/* and *http://wireless.ictp.trieste.it/* for more details on those courses and their material. Additional information was provided by the International Network for the Availability of Scientific Publications, *http://www.inasp.info/*. Some of this material has been incorporated directly into this book. Additional material was adapted from *How To Accelerate Your Internet*, *http://bwmo.net/*.

Credits

This book was started as the BookSprint project at the 2005 session of WSFII, in London, England (*http://www.wsfii.org/*). A core team of seven people built the initial outline over the course of the event, presented the results at the conference, and wrote the book over the course of a few months. Throughout the project, the core group has actively solicited contributions and feedback from the wireless networking community. Add your own feedback and updates to the WNDW wiki at *http://wiki.wndw.net/*.

- **Rob Flickenger** was the lead author and editor of this book. Rob has written and edited several books about wireless networking and Linux, including *Wireless Hacks* (O'Reilly Media) and *How To Accelerate Your Internet* (*http://bwmo.net/*). He is proud to be a hacker, amateur mad scientist, and proponent of free networks everywhere.

- **Corinna "Elektra" Aichele**. Elektra's main interests include autonomous power systems and wireless communication (antennas, wireless long shots, mesh networking). She made a small linux distro based on slackware geared to wireless mesh networking. This information is of course redundant if one reads the book... *http://www.scii.nl/~elektra*

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countries and released over 600 pages of documentation under Creative Commons License. More information can be found at *http://www.it46.se/*

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- **Ian Howard.** After flying around the world for seven years as a paratrooper in the Canadian military, Ian Howard decided to trade his gun for a computer.

  After finishing a degree in environmental sciences at the University of Waterloo he wrote in a proposal, "Wireless technology has the opportunity to bridge the digital divide. Poor nations, who do not have the infrastructure for interconnectivity as we do, will now be able to create a wireless infrastructure." As a reward, Geekcorps sent him to Mali as the Geekcorps Mali Program Manager, where he led a team equipping radio stations with wireless interconnections and designed content sharing systems.

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  Tomas is also an associate of the Tactical Technology Collective *http://www.tacticaltech.org/*, an Amsterdam-based non-profit "to strengthen social technology movements and networks in developing and transition countries, as well as promote civil society's effective, conscious and creative use of new technologies." Currently most of his energy goes into the Wireless Roadshow (*http://www.thewirelessroadshow.org/*), a project that supports civil society partners in the developing world in planning, building and sustaining connectivity solutions based on license-exempt spectrum, open technology and open knowledge.

- **Gina Kupfermann** is graduate engineer in energy management and holds a degree in engineering and business. Besides her profession as financial controller she has worked for various self-organised community projects and non-profit organisations. Since 2005 she is member of the executive board of the development association for free networks, the legal entity of freifunk.net.

- **Adam Messer**. Originally trained as an insect scientist, Adam Messer metamorphosed into a telecommunications professional after a chance conversation in 1995 led him to start one of Africa's first ISPs. Pioneering wireless data services in Tanzania, Messer worked for 11 years in eastern and southern Africa in voice and data communications for startups and multinational cellular carriers. He now resides in Amman, Jordan.

- **Juergen Neumann** (*http://www.ergomedia.de/*) started working with information technology in 1984 and since then has been looking for ways to deploy ICT in useful ways for organizations and society. As a consultant for ICT strategy and implementation, he has worked for major German and international companies and many non-profit projects. In 2002 he co-founded *www.freifunk.net*, a campaign for spreading knowledge and social networking about free and open networks. Freifunk is globally regarded as one of the most successful community-projects in this field.

- **Ermanno Pietrosemoli** has been involved in planning and building computer networks for the last twenty years. As president of the Latin American Networking School, Escuela Latinoamericana de Redes "EsLaRed", *www.eslared.org.ve*, he has been teaching wireless data communications in several countries while keeping his base at Mérida, Venezuela.

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- **Marco Zennaro**, aka marcusgennaroz, is an electronic engineer working at the ICTP in Trieste, Italy. He has been using BBSes and ham radios since he was a teenager, and he is happy to have merged the two together working in the field of wireless networking. He still carries his Apple Newton.

Support

- **Lisa Chan** (*http://www.cowinanorange.com/*) was the lead copy editor.

- **Casey Halverson** (*http://seattlewireless.net/~casey/*) provided technical review and suggestions.

- J**essie Heaven Lotz** (http://jessieheavenlotz.com/) provided several updated illustrations for this edition.

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- **Catherine Sharp** (*http://odessablue.com/*) provided copy edit support.

- **Lara Sobel** designed the cover for WNDW 2nd Edition. She is an artist currently living in Seattle, WA.

- **Matt Westervelt** (*http://seattlewireless.net/~mattw/*) provided technical review and copy edit support. Matt is the founder of SeattleWireless (*http://seattlewireless.net/*) and is an evangelist for FreeNetworks worldwide.

About the solar power guide

The source material for the Solar Power chapter was translated and developed by Alberto Escudero-Pascual. In 1998, the organization Engineering without Borders (Spanish Federation) published the first version of a handbook titled "Manual de Energía Solar Fotovoltaica y Cooperación al Desarrollo". The handbook was written and published by members of the NGO and experts of the Institute of Energy Solar of the Polytechnical University of Madrid. By curiosities of life, none of the members of the editorial team kept the document in electronic format and more editions were never made. They have passed almost ten years from that very first edition and this document is an effort to rescue and to extend the handbook.

As part of this rescue operation Alberto would like to thank the coordinators of the first original edition and his mentors in his years at University: Miguel Ángel Eguido Aguilera, Mercedes Montero Bartolomé y Julio Amador. This new work is licensed under Creative Commons **Attribution-ShareAlike 3.0**. We hope that this material becomes a new departure point for new editions including new contributions by the community.

This second and extended edition of the solar power guide has received valuable input from Frédéric Renet and Louise Berthilson.

Special thanks

The core team would like to thank the organizers of WSFII for providing the space, support, and occasional bandwidth that served as the incubator for this project. We would especially like to thank community networkers everywhere, who devote so much of their time and energy towards fulfilling the promise of the global Internet. Without you, community networks could not exist.

IDRC ❋ CRDI

The Abdus Salam
International Centre
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1
Where to Begin

This book was created by a team of individuals who each, in their own field, are actively participating in the ever-expanding Internet by pushing its reach farther than ever before. The massive popularity of wireless networking has caused equipment costs to continually plummet, while equipment capabilities continue to sharply increase. We believe that by taking advantage of this state of affairs, people can finally begin to have a stake in building their own communications infrastructure. We hope to not only convince you that this is possible, but also show how we have done it, and to give you the information and tools you need to start a network project in your local community.

Wireless infrastructure can be built for very little cost compared to traditional wired alternatives. But building wireless networks is only partly about saving money. By providing people in your local community with cheaper and easier access to information, they will directly benefit from what the Internet has to offer. The time and effort saved by having access to the global network of information translates into wealth on a local scale, as more work can be done in less time and with less effort.

Likewise, the network becomes all the more valuable as more people are connected to it. Communities connected to the Internet at high speed have a voice in a global marketplace, where transactions happen around the world at the speed of light. People all over the world are finding that Internet access gives them a voice to discuss their problems, politics, and whatever else is important to their lives, in a way that the telephone and television simply cannot compete with. What has until recently sounded like science fiction is now becoming a reality, and that reality is being built on wireless networks.

But even without access to the Internet, wireless community networks have tremendous value. They allow people to collaborate on projects across wide distances. Voice communications, email, and other data can be exchanged for very little cost. By getting local people involved in the construction of the network, knowledge and trust are spread throughout the community, and people begin to understand the importance of having a share in their communications infrastructure. Ultimately, they realize that communication networks are built to allow people to connect with each other.

In this book we will focus on wireless data networking technologies in the 802.11 family. While such a network can carry data, voice, and video (as well as traditional web and Internet traffic), the networks described in this book are data networks. We specifically do not cover GSM, CDMA, or other wireless voice technologies, since the cost of deploying these technologies is well beyond the reach of most community projects.

Purpose of this book

The overall goal of this book is to help you build affordable communication technology in your local community by making best use of whatever resources are available. Using inexpensive off-the-shelf equipment, you can build high speed data networks that connect remote areas together, provide broadband network access in areas that even dialup does not exist, and ultimately connect you and your neighbors to the global Internet. By using local sources for materials and fabricating parts yourself, you can build reliable network links with very little budget. And by working with your local community, you can build a telecommunications infrastructure that benefits everyone who participates in it.

This book is not a guide to configuring a radio card in your laptop or choosing consumer grade gear for your home network. The emphasis is on building infrastructure links intended to be used as the backbone for wide area wireless networks. With that goal in mind, information is presented from many points of view, including technical, social, and financial factors. The extensive collection of case studies present various groups' attempts at building these networks, the resources that were committed to them, and the ultimate results of these attempts.

Since the first spark gap experiments at the turn of the last century, wireless has been a rapidly evolving area of communications technology. While we provide specific examples of how to build working high speed data links, the techniques described in this book are not intended to replace existing wired infrastructure (such as telephone systems or fiber optic backbone). Rather, these techniques are intended to augment existing systems, and provide connectivity in areas where running fiber or other physical cable would be impractical.

We hope you find this book useful for solving your communication challenges.

Fitting wireless into your existing network

If you are a network administrator, you may wonder how wireless might fit into your existing network infrastructure. Wireless can serve in many capacities, from a simple extension (like a several kilometer Ethernet cable) to a distribution point (like a large hub). Here just a few examples of how your network can benefit from wireless technology.
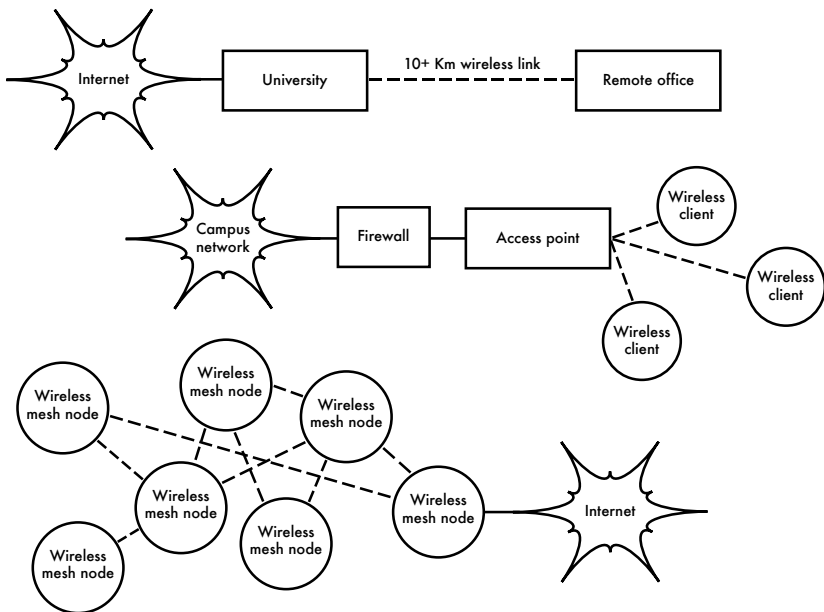
Figure 1.1: Some wireless networking examples.

Wireless networking protocols

The primary technology used for building low-cost wireless networks is currently the 802.11 family of protocols, also known in many circles as **Wi-Fi**. The 802.11 family of radio protocols (802.11a, 802.11b, and 802.11g) have enjoyed an incredible popularity in the United States and Europe. By implementing a common set of protocols, manufacturers world wide have built highly interoperable equipment. This decision has proven to be a significant boon to the industry and the consumer. Consumers are able to use equipment that implements 802.11 without fear of "vendor lock-in". As a result, consumers are able to purchase low-cost equipment at a volume which has benefitted manufacturers. If manufacturers had chosen to implement their

own proprietary protocols, it is unlikely that wireless networking would be as inexpensive and ubiquitous as it is today.

While new protocols such as 802.16 (also known as WiMax) will likely solve some difficult problems currently observed with 802.11, they have a long way to go to match the popularity and price point of 802.11 equipment. As equipment that supports WiMax is just becoming available at the time of this writing, we will focus primarily on the 802.11 family.

There are many protocols in the 802.11 family, and not all are directly related to the radio protocol itself. The three wireless standards currently implemented in most readily available gear are:

• **802.11b**. Ratified by the IEEE on September 16, 1999, 802.11b is probably the most popular wireless networking protocol in use today. Millions of devices supporting it have shipped since 1999. It uses a modulation called *Direct Sequence Spread Spectrum* (*DSSS*) in a portion of the ISM band from 2.400 to 2.495 GHz. It has a maximum rate of 11 Mbps, with actual usable data speeds up to about 5 Mbps.

• **802.11g**. As it wasn't finalized until June 2003, 802.11g is a relative latecomer to the wireless marketplace. Despite the late start, 802.11g is now the de facto standard wireless networking protocol as it now ships as a standard feature on virtually all laptops and most handheld devices. 802.11g uses the same ISM range as 802.11b, but uses a modulation scheme called *Orthogonal Frequency Division Multiplexing* (*OFDM*). It has a maximum data rate of 54 Mbps (with usable throughput of about 22 Mbps), and can fall back to 11 Mbps DSSS or slower for backwards compatibility with the hugely popular 802.11b.

• **802.11a**. Also ratified by the IEEE on September 16, 1999, 802.11a uses OFDM. It has a maximum data rate of 54 Mbps, with actual throughput of up to 27 Mbps. 802.11a operates in the ISM band between 5.745 and 5.805 GHz, and in a portion of the UNII band between 5.150 and 5.320 GHz. This makes it incompatible with 802.11b or 802.11g, and the higher frequency means shorter range compared to 802.11b/g at the same power. While this portion of the spectrum is relatively unused compared to 2.4 GHz, it is unfortunately only legal for use in a few parts of the world. Check with your local authorities before using 802.11a equipment, particularly in outdoor applications. 802.11a equipment is still quite inexpensive, but is not nearly as popular as 802.11b/g.

In addition to the above standards, there are a number of vendor-specific extensions to equipment, touting higher speeds, stronger encryption, and increased range. Unfortunately these extensions will not operate between equipment from different manufacturers, and purchasing them will effectively lock you into that vendor for every part of your network. New equipment and standards (such as

802.11y, 802.11n, 802.16, MIMO and WiMAX) promise significant increases in speed and reliability, but this equipment is just starting to ship at the time of this writing, and availability and vendor interoperability is still uncertain.

Due to the ubiquity of equipment and unlicensed nature of the 2.4 GHz ISM band, this book will concentrate on building networks using 802.11b and 802.11g.

Question & Answer

If you are new to wireless networking, you likely have a number of questions about what the technology can do and what it will cost. Here are some commonly asked questions, with answers and suggestions on the listed page.

Power

- How can I supply power to my radio equipment, if there is no grid power available? **Page 211**
- Do I need to run a power cable all the way up the tower? **Page 250**
- How can I use solar panel to power my wireless node while keeping it online overnight? **Page 217**
- How long will my access point run on a battery? **Page 238**
- Can I use a wind generator to power my equipment at night? **Page 212**

Management

- How much bandwidth will I need to purchase for my users? **Page 65**
- How can I monitor and manage remote access points from my office? **Page 174**
- What do I do when the network breaks? **Page 174, 267**
- What are the most common problems encountered on wireless networks, and how do I fix them? **Page 267**

Distance

- How good is the range of my access point? **Page 67**
- Is there any formula I can use to know how far I can go with a given access point? **Page 67**
- How can I know if a remote place can be connected to Internet using a wireless link? **Page 67**
- Is there any software that can help me estimate the feasibility of a long distance wireless link? **Page 74**

- The manufacturer says my access point has a range of 300 meters. Is that true? **Page 67**
- How can I provide wireless connectivity to many remote clients, spread all around the city? **Page 53**
- Is it true that I can reach a much greater distance adding a tin can or aluminum foil to my AP's antenna? **Page 116**
- Can I use wireless to connect to a remote site and share a single central Internet connection? **Page 51**
- My wireless link looks like it will be too long to work well. Can I use a repeater in the middle to make it better? **Page 77**
- Should I use an amplifier instead? **Page 115**

Installation

- How can I install my indoor AP on the top of a mast on my roof? **Page 249**
- Is it really useful to add a lightning protector and proper grounding to my antenna mast, or can I go without them? **Page 263**
- Can I build an antenna mast by myself? How high can I go? **Page 251**
- Why does my antenna work much better when I mount it "sideways"? **Page 13**
- Which channel should I use? **Page 15**
- Will radio waves travel through buildings and trees? What about people? **Page 16**
- Will radio waves travel through a hill that is in the way? **Page 17**
- How do I build a mesh network? **Page 56**
- What kind of antenna is the best one for my network? **Page 102**
- Can I build an access point using a recycled PC? **Page 143**
- How can I install Linux on my AP? Why should I do so? **Page 152**

Money

- How can I know if a wireless link is achievable with a limited amount of money? **Page 281**
- Which is the best AP with the lowest price? **Page 137**
- How can I track and bill customers for using my wireless network? **Page 165, 190**

Partners and Customers

- If I am supplying connectivity, do I still need service from an ISP? Why? **Page 27**

- How many customers do I need to cover my costs? **Page 287**

- How many customers will my wireless network support? **Page 65**

- How do I make my wireless network go faster? **Page 79**

- Is my Internet connection as fast as it can be? **Page 90**

Security

- How can I protect my wireless network from unauthorized access? **Page 157**

- Is it true that a wireless network is always insecure and open to attacks by hackers? **Page 160**

- Is it true that the use of open source software makes my network less secure? **Page 167**

- How can I see what is happening on my network? **Page 174**

Information and Licensing

- What other books should I read to improve my wireless networking skills? Page 355

- Where can I find more information online? **Page 349,** *http://wndw.net/*

- Can I use parts of this book for my own teaching? Can I print and sell copies of this book? **Yes.** See **About This Book** for more details.

2

A Practical Introduction to Radio Physics

Wireless communications make use of electromagnetic waves to send signals across long distances. From a user's perspective, wireless connections are not particularly different from any other network connection: your web browser, email, and other applications all work as you would expect. But radio waves have some unexpected properties compared to Ethernet cable. For example, it's very easy to see the path that an Ethernet cable takes: locate the plug sticking out of your computer, follow the cable to the other end, and you've found it! You can also be confident that running many Ethernet cables alongside each other won't cause problems, since the cables effectively keep their signals contained within the wire itself.

But how do you know where the waves emanating from your wireless card are going? What happens when these waves bounce off of objects in the room or other buildings in an outdoor link? How can several wireless cards be used in the same area without interfering with each other?

In order to build stable high-speed wireless links, it is important to understand how radio waves behave in the real world.

What is a wave?

We are all familiar with vibrations or oscillations in various forms: a pendulum, a tree swaying in the wind, the string of a guitar - these are all examples of oscillations.

What they have in common is that something, some medium or object, is swinging in a periodic manner, with a certain number of cycles per unit of time. This kind of wave is sometimes called a **mechanical wave**, since it is defined by the motion of an object or its propagating medium.

When such oscillations travel (that is, when the swinging does not stay bound to one place) then we speak of waves propagating in space. For example, a singer singing creates periodic oscillations in his or her vocal cords. These oscillations periodically compress and decompress the air, and this periodic change of air pressure then leaves the singers mouth and travels, at the speed of sound. A stone plunging into a lake causes a disturbance, which then travels across the lake as a **wave**.

A wave has a certain **speed**, **frequency**, and **wavelength**. These are connected by a simple relation:

```
Speed = Frequency * Wavelength
```

The wavelength (sometimes referred to as **lambda**, **λ**) is the distance measured from a point on one wave to the equivalent part of the next, for example from the top of one peak to the next. The frequency is the number of whole waves that pass a fixed point in a period of time. Speed is measured in meters/second, frequency is measured in cycles per second (or Hertz, abbreviated **Hz**), and wavelength is measured in meters.

For example, if a wave on water travels at one meter per second, and it oscillates five times per second, then each wave will be twenty centimeters long:

```
1 meter/second = 5 cycles/second * W
W = 1 / 5 meters
W = 0.2 meters = 20 cm
```

Waves also have a property called **amplitude**. This is the distance from the center of the wave to the extreme of one of its peaks, and can be thought of as the "height" of a water wave. The relationship between frequency, wavelength, and amplitude are shown in **Figure 2.1**.

Waves in water are easy to visualize. Simply drop a stone into the lake and you can see the waves as they move across the water over time. In the case of electromagnetic waves, the part that might be hardest to understand is: "What is it that is oscillating?"

In order to understand that, you need to understand electromagnetic forces.