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H4.SMR/1132-20

SECOND ICTP - URSI - ITU/BDT SCHOOL ON THE USE OF RADIO FOR DIGITAL COMMUNICATIONS IN DEVELOPING COUNTRIES, INCLUDING SPECTRUM MANAGEMENT

(1 - 19 February, 1999)

SPREAD SPECTRUM RADIO TECHNOLOGIES

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Spread Spectrum radio Technologies

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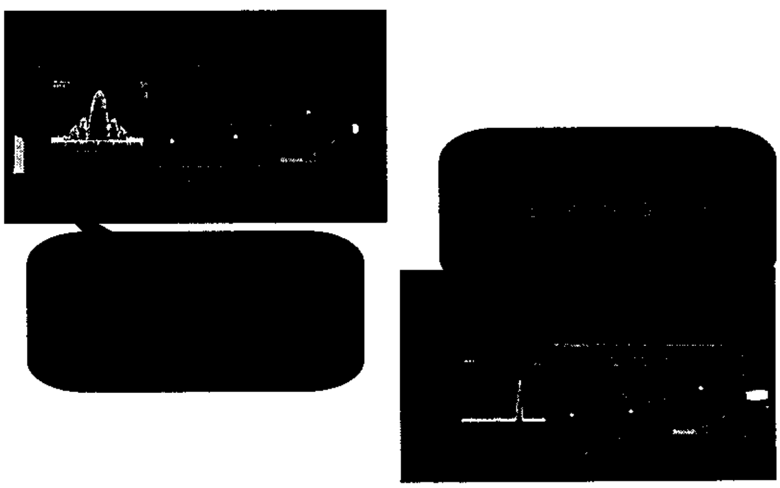
We will speak about

- *Spread Spectrum vs. Narrow Band*
- *Benefits of Spread Spectrum*
- *Direct Sequence Spread Spectrum*
- *Frequency Hopping Spread Spectrum*
- *Frequency Hopping vs. Direct Sequence*
- *Antenna Basics*
- *Power Budget Calculation*

Spread Spectrum vs. Narrow Band

- Spread Spectrum Signal Characteristics
  - The bandwidth of the transmitted signal is much greater than the original message bandwidth
  - The bandwidth of the transmitted signal is determined by a spreading function (code), independent of the message, and known only to transmitter and receiver

Spread Spectrum vs. Narrow Band



Spread Spectrum vs. Narrow Band

	Narrow Band Data Modulation	Spread Spectrum Data Modulation
Power Density	The energy of the transmitted signal is concentrated close to the carrier frequency. High energy in a part of the band	The energy of the signal is distributed (spread) in all the frequencies. Low energy in all the band
Actual Power Density	The actual power density is determined by the data signal (to be transmitted)	The actual power density is determined by the data and a specific (data independent) code (redundant transmission)
Geographical Coverage	Concentration of energy => High energy level => Greater coverage	Spread Energy => Low power density => Small coverage
Bandwidth (Round Figures)	Small BW AM=4kHz FMw=15kHz FMn=8kHz TV=5MHz	Large BW 902-928 MHz 2.400 2.485 GHz 5.720 5.850 GHz
System Colocation	Archived by frequency allocation. There's a limit of system for a given BW and band	Archived by using different codes (CDMA) There's in any case a limit
Noise Immunity	Archived by increasing the power of the carrier	The information is present all over the band in a reduntand way. The system use the code "to look for" his partners. Is a very unlucky situation to have noise at the same time in the whole band, therefore information can be reconstructed.

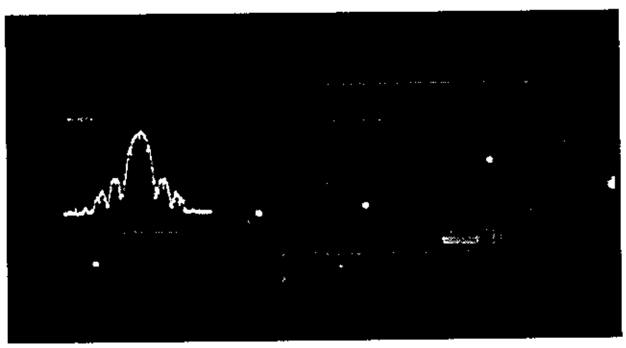
Benefits of Spread Spectrum

- *Do not interfere with other signals (spread or narrow)*
- *Are immune to interference generated by other signals (spread or narrow) present in the frequency band*
- *Hard to intercept (CODE)*
- *Can be physically co-located*
- *License free operation (CEPT TR-1001)*
- *Resistance to jamming*

Direct Sequence Spread Spectrum

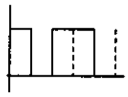
- **May be seen as result of two processes**
  - *Data is multiplied with a higher rate digital sequence (spreading code). The sequence has many "chips" for every data bit;*
  - *The resultant signal modulate the RF carrier.*
- **Effects of Direct Sequence spreading**
  - *Data bit information is carried in every "chip";*
  - *If the noise do not affect all the "chips", the information can be recovered. Chips are done in a way that they are easily recognizable;*
  - *The capacity of a system to reconstruct data is a function of the ratio Tbit/Tchip=Process Gain (Usually PG>10);*
  - *Multiple system can co-exist in the same band if they use different (orthogonal) spreading sequence;*
  - *Spreading seq. tend to be very long, requiring high BW.*

Direct Sequence Spread Spectrum



Direct Sequence Spread Spectrum

To transmit a 0 the station use a unique "chip sequence":

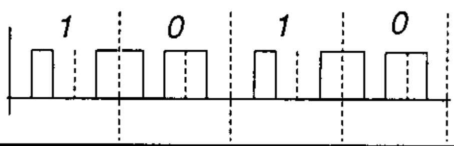


1 0 1 1 0

To transmit a 1 the station use the one's complement of its chip sequence:

0 1 0 0 1

Therefore if data is 1010 it will transmit:



Direct Sequence Spread Spectrum

- *It is more convenient to use a bipolar notation where 0 = -1 and 1 = +1.*
- *With this new notation the two chip sequences becomes:*
  - *(+1,-1,+1,+1,-1)*
  - *(-1,+1,-1,-1,+1)*
- *As we said before if another group of stations wants to share the same band they have to use different chip sequences :*
  - *S= sequence for 0 of group A* $\bar{S}$*= sequence for 1 of group A*
  - *T= sequence for 0 of group B* $\bar{T}$*= sequence for 1 of group B*
- *They must be pairwise orthogonal therefore the normalized inner product must be 0:*

$$S \bullet T \equiv \frac{1}{m}\sum_{i=1}^{m} S_i \cdot T_i = 0$$

- *In practice as many pairs are the same as are different*
- *Important notice:*
  - $S{*}T=0,\ S{*}\bar{T}=0,\ S{*}S=1,\ S{*}\bar{S}=-1$

Direct Sequence Spread Spectrum

- *A good sequence with all this features is the so called Pseudo Noise sequence (PN)*
- *A PN sequence of a given length is orthogonal (CROSS CORRELATION COEFFICENT =0) with all the other PN sequences of the same length*
- *It has a good AUTO CORRELATION behavior, in fact the CORRELATION COEFFICENT of a sequence, correlated to a shifted version of itself, is close to 0 (this is a very important factor during synchronization)*

Direct Sequence Spread Spectrum

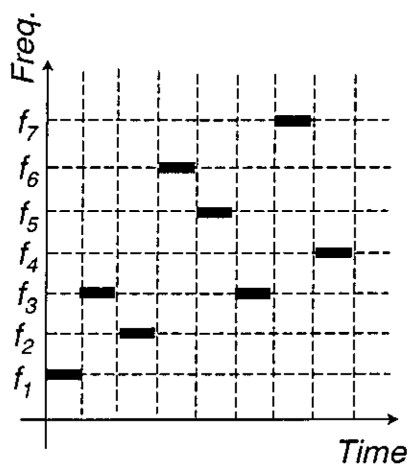
- *When two or more stations transmit simultaneously (using different codes) the bipolar signals add linearly, like adding voltages;*
- *To recover the bit stream of an individual station, the receiver has to :*
  - *know the chip sequence used by that station*
  - *compute the inner normalized product between the received sequence and the chip sequence of the station; let's assume that:*
    - *station A transmit* S
    - *station B transmit* $\overline{T}$
    - *we ,station C, receive* $(S+\overline{T})$
    - *we want to see what A was transmitting:*
    - $(S+\overline{T})*S=S*S+S*\overline{T}=1+0=1$
- *As we see station A was transmitting a 1*
- *This, in any case, is an ideal situation because we assumed that the tree station where perfectly synchronized and there were no noise ... in any case up to a certain extent the decoding algorithm works quite well ...*

Frequency Hopping Spread Spectrum

- May be seen as result of two processes
  - *Data modulate the RF carrier;*
  - *The center frequency of the RF carrier is modified based on a spreading sequence.*
- Effects of Frequency Hopping spreading
  - *Data is carried on all the frequency hops;*
  - *If the noise do not affect all the hops, the information can be recovered;*
  - *Multiple system can co-exist in the same band if they use different spreading sequences.*

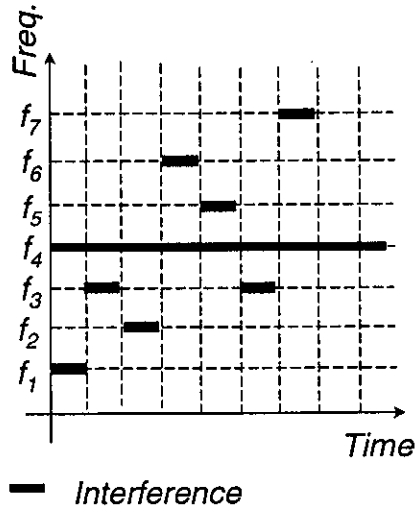
Frequency Hopping Spread Spectrum

- Transmitted signal is spread over a wide range of frequencies. (i.e. 2.400-2.485 GHz)
- Transmission usually hop 35 times per second.



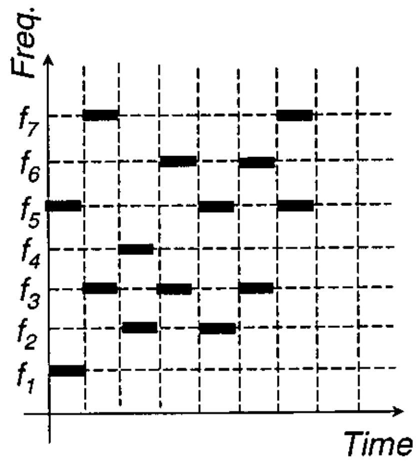
Frequency Hopping Spread Spectrum

- Low probability of interception.
- Jamming and interference immunity.



Frequency Hopping Spread Spectrum

- Co-existence of two systems.
- No near/far problem.

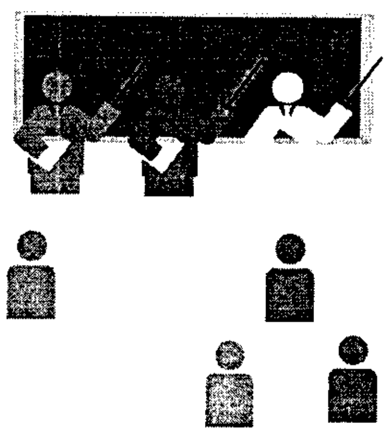


Frequency Hopping vs. Direct Sequence

- System co-location
  - DS require very high speed for the "spreading code", much higher that the transmitted data.
- Interference rejection
  - DS systems accept levels of interference a little bit higher that those accepted by FS systems;
  - However if the interference is higher than the limit the DS stop to work but the FS try to use unaffected frq. and continue to work.

Frequency Hopping vs. Direct Sequence

- DS systems are affected by high levels of interference created by other DS systems using the same band but different codes.
- FH can always use unblocked hops.



Frequency Hopping vs. Direct Sequence

- Multipath
  - DS systems use very high transmission rates => very short symbols that are more sensitive to echoes and delays.
- Throughput
  - DS systems transmit continuously (PSK). FS spend some time to re-synchronize and for hopping (FSK);
  - DS systems may have a better throughput for same data rate over the air.
- Radio Complexity
  - DS use more complex radios.

Antenna Basics

Antenna Basics

- Transmission Line
  - The device used to guide the RF energy from one point to another.
- Radio Antenna
  - The structure associated with the region of transition from a guided wave to a free space wave, radiating RF energy.

Antenna Basics - UNITS

- How do we measure power:
  - [dBm]=10 Log [mW]

dbm	watt
0	0.001
10	0.01
20	0.1
30	1
40	10

Antenna Directivity

- Isotropic Antenna
  - Radiates the energy fed into it in the whole space.
- Non Isotropic Antenna
  - Radiates energy fed into it only in part of the space.

Antenna Directivity & Gain

- Non isotropic antennas are characterized by their capability to radiate more strongly in some directions than in others; this is called directivity.
- The ratio of the maximum power density to the average power density over the entire space is the numerical measure of directivity that is:

$$D = \frac{P}{P_{av}} \qquad D[dBi] = 10Log_{10}\left(\frac{P}{P_{av}}\right)$$

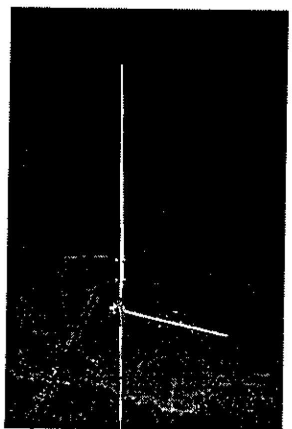
Antenna Directivity & Gain

- *The gain is closely related to directivity. In this case you have to take into account the efficiency (k) of the antenna:*

$$G = k\frac{P}{P_{av}}$$

- *For most of the antenna systems used, efficiency is quite high, in such cases the gain is essentially equal to directivity*

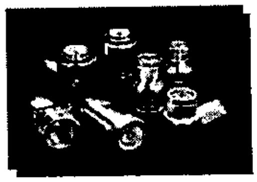
Antenna Types

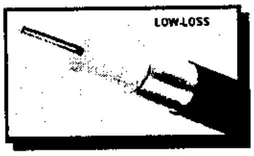


- *Omni Directional Antenna*

- *YAGI Directional Antenna*

Transmission Lines ,Cables and Connectors



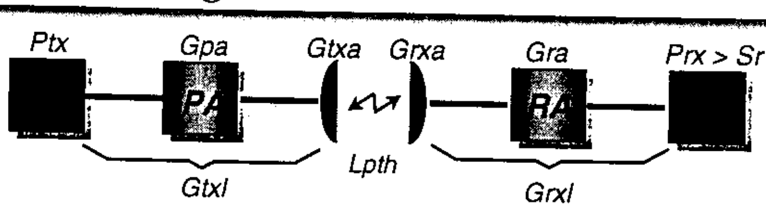


Type	Typycal attenuation @ 2.400GHz
RG58	1 dB/m
RG214	0.6 dB/m
Heliax	0.14 dB/m

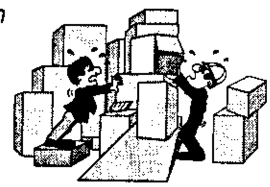
Power Budget Calculation

- *What is the distance limitation for RADIO LINKS ?*
  - *Generally, transmission range is limited to "unobstructed line-of-sight" The transmission range is influenced by the*
  - *transmitter power*
  - *type and location of the antenna*
  - *frequency*
  - *length of the antenna feed line (the cable connecting the radio to the antenna).*
  - *Another factor influencing the transmission range is the existence of obstructions (hills, groups of buildings ,etc).*

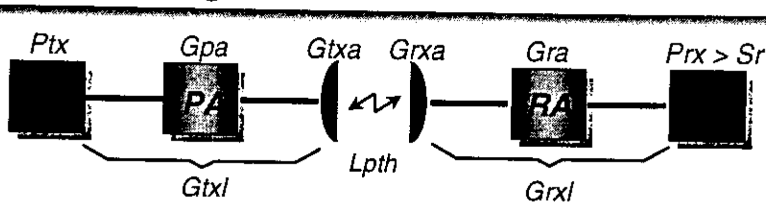
Power Budget Calculation



- Ptx[dBm]=Power generated by TX
- Gpa[dB]=Gain of the Power Amplifier
- Gtxl[dB]=Gain (loss) of transmission line
- Gtxa[dBi]=Gain of TX antenna
- Lpth[dB]=Loss of the transmission medium
- Grxa[dBi]=Gain of RX antenna
- Grxl[dB]=Gain (loss) of receiving line
- Gra[dB]=Gain of the Receive Amplifier
- Prx[dBm]=Power received
- Sr[dBm]=Sensivity of receiver Gtxl



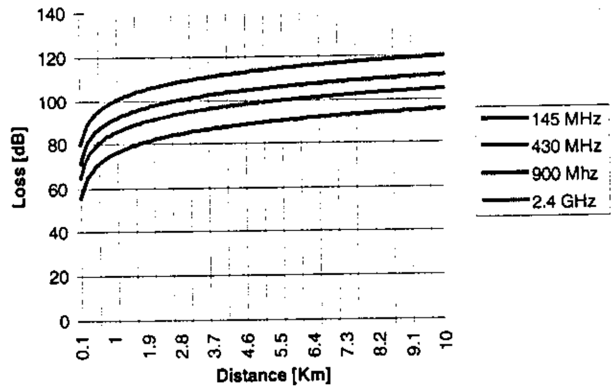
Power Budget Calculation



- Prx=Ptx+Gpa-Gtxl+Gtxa-Lpth+Grxa+Gra-Grxl
- Prx > Sr

Power Budget Calculation

- Loss of TRANSMISSION medium:



$$Lpth[dB] = 92.5 + 20 \cdot Log_{10} f[GHz] + 20 \cdot Log_{10} d[Km]$$

Spread Spectrum radio Technology

The end. Relax

Installation of a Spread Spectrum Frequency Hopping Wireless Network

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Task 1: Install Wireless STATION ADAPTER for the ROUTER

Objectives:	To physically connect the Breezecom STATION ADAPTER to the PC
Method:	Using a RJ45 (UTP) patch cord
Comments:	All antennas must be connected before powering on the equipments

Activity 1.1

Locate on the PC the card that will be dedicated to the wireless LAN and connect it to the STATION ADAPTER.

Task 2: Install the ACCESS POINT for the Computer Centre

Objectives:	To install the Breezecom ACCESS POINT in order to let the SAs to see each other
Method:	Using a free port of a HUB (Switch) and a normal patch cord or by mean of a cross patch cord directly to a Ethernet port of a PC
Comments:	Beeing the Breezcom a POINT to MULTIPOINT system, is necessary to have a Master Station that controls the network, provide the rigth timing for the remote stations to access the radio media, and to let them to speak together

Activity 2.1

Locate a free port on the laboratory HUB and using a patch cord connect the unit.

Task 3:Test & Measurements

Objectives:	Test the connectivity - Test the Signal Quality
Method:	Using the command : **ping** - Using the configuration port installed on each unit and a terminal emulation program (MINICOM)
Comments:	Pay attention and comment the information that appears on the screen

Activity 3.1 Ping the different ROUTERS

```
linuxXX:~# ping  -f 140.105.46.###
```

Activity 3.3 Test link parameters

Connect the configuration cable to your PC, run minicom -s line parameters are : LINE = /dev/ttyS0 SPEED=9600 8 N 1 on it and follow the instructions that will appear on the screen

Installation of a Spread Spectrum Direct Sequence Wireless Network

1. Install Wireless Network Card for the ROUTER
2. Make the KERNEL able to recognize the Wireless Card
3. Install a WAVEPOINT
4. Test & Measurements

Task 1: Install Wireless Network Card for the ROUTER

Objectives:	To physically insert the Wavelan card into the PC
Method:	Using the software provided with the card or dip switches following the card instructions
Comments:	Be sure that there's no IRQ or IO/BASE conflicts (i.e IO-BASE=0x390 IRQ=12)

Activity 1.1

Shut down the LINUX router.
Open the PC, remove the NIC (Network Interface Card) that was connected to the BACKBONE and in place of it insert the Wavelan. Connect the small PATCH antenna.

Task 2: Make the KERNEL able to recognize the Wireless Network Card

Objectives:	To install and configure a LINUX machine to accept the Wireless Network Card
Method:	Modify **/etc/lilo.conf**
Comments:	There are two methods to configure LINUX kernel to recognize and use a NIC in general; the first one is to compile the kernel with the proper drivers as part of the code. The second one, more efficient, is using a feature called MODULES: in this case a set of drivers for all the possible devices is compiled but it is not part of the kernel; al the boot time or whenever required it is possible to install only what is required.

Activity 2.1

In our case the KERNEL is already compiled with the support for the WAVELAN.
Move to /etc/ directory:

```
linuxXX:~# cd /etc/
```

Activity 2.2

Edit the file called lilo.conf:

```
linuxXX:~# pico -w lilo.conf

UW PICO(tm) 2.9                File: lilo.conf

append = "ether=0,0,eth0 ether=0,0x390,eth1"
boot=/dev/hda
map=/boot/map
install=/boot/boot.b
prompt
timeout=50
image=/boot/vmlinuz-2.0.36
        label=linux
        root=/dev/hda1
        read-only




                          [ Read 11 lines ]
^G Get Help  ^O WriteOut  ^R Read File ^Y Prev Pg   ^K Cut Text  ^C Cur Pos
^X Exit      ^J Justify   ^W Where is  ^V Next Pg   ^U UnCut Text^T To Spell
```

Activity 2.3

After having modified lilo.conf you **must run lilo** to load it into the system, and reboot the PC to load the new configuration.

```
linuxXX:~# lilo
linuxXX:~# reboot
```

Activity 2.4

Save the file (^X) and reboot the PC. **Pay attention to the messages coming on the screen, there should be one or more message lines with eth# (eth0 , eth1)**
If not ?

Task 3: Install a WAVEPOINT

Objectives: To install a WAVEPOINT

Method: Connect it to the HUB

Comments: BE sure that the NWID are the same within all the unit that belongs to the wireless lan.

Activity 3.1

Locate a HUB to connect the WAVEPOINT and connect it using a patch cable.

Task 4:Test & Measurements

Objectives: Test the connectivity - Test the Signal Quality

Method: Using the command : **ping** - Using the software **PTPDIAG** that comes with the card

Comments: Pay attention and comment the information that appears on the screen

Activity 4.1 Ping the different ROUTERS

```
linuxXX:~# ping  -f 140.105.46.###
```

Activity 4.2 Test the throughput with a file transfer

```
linuxXX:~# ftp 140.105.46.###
Connected to 140.105.46.###.
220 sv2 FTP server (UNIX(r) System V Release 4.0) ready.
Name (140.105.38.5:root): root
331 Password required for root.
Password:
530 User logged in.
ftp> bin
200 Type set to I.
ftp> get test_file
local: test_file remote: test_file
200 PORT command successful.
150 Binary data connection for test_file (140.105.46.###,3162) (xxxxxxxx bytes).
226 Binary Transfer complete.
4965 bytes received in yyyyyy secs (yyyyyy Kbytes/sec)
ftp> bye
```

Activity 3.3 Test link parameters

On the Wireless ROUTERS boot the PC in dos (Note that all the PC's connected to the Local Network, while the router is in DOS are out of the rest of the network ..) run **PTPDIAG** on, al least, two Routers and check the S/N Ratio.