Intelligent Adaptation

And

Cognitive Networking

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Media

- Wired
  - Can react to local conditions near speed of light
  - Generally reactive systems rather than predictive work “good enough”
- Wireless
  - Much slower sensory and response time
  - Multiple systems can react simultaneously, and not see each other’s effects
  - Broadcast costs and power generally cause a greedy, best-effort scheme

Frequency and Spectrum Usage

- In USA, limited legal usage of wireless frequency (~2.4 and 5 GHz most used)
- ISM (Industrial, Scientific, Medical) bands tend to get overloaded
- Open areas rarely utilized, due to standardization of use

Charts courtesy of commandline.net:

Remote Control Airplanes

27 MHZ Air and Land Use

Ch	Freq
A1	26.995
A2	27.045
A3	27.095
A4	27.145
A5	27.195
A6	27.255

50 MHZ FCC License Required

Ch	Freq
00	50.800
01	50.820
02	50.840
03	50.860
04	50.880
05	50.900
06	50.920
07	50.940
08	50.960
09	50.980

72 MHZ Aircraft Only

Ch	Freq
11	72.010
12	72.030
13	72.050
14	72.070
15	72.090
16	72.110
17	72.130
18	72.150
19	72.170
20	72.190
21	72.210
22	72.230

75 MHZ Land Use Only

Ch	Freq
61	75.410
62	75.430
63	75.450
64	75.470
65	75.490
66	75.510
67	75.530
68	75.550
69	75.570
70	75.590
71	75.610
72	75.630

HAM Radio

Medium Frequency (MF) (300 kHz to 3 MHz)
High Frequency (HF) (3.0 - 30.0 MHz)
Very High Frequency (VHF) (30 to 300 MHz)
Ultra High Frequency (UHF) (300 MHz to 3 GHz)
Super High Frequency (SHF) (3 to 30 GHz)
Extremely High Frequency (EHF) (30 to 300 GHz)

Through ITU (International Telecommunication Union) agreement bandwidth has been set aside for amateur transmissions. Amateurs use a variety of transmission modes, including Morse code, radio teletype, data, and voice. Specific frequency allocations are a matter of record and vary from country to country and region to region, but the frequency allocations in the USA are:

Medium Frequency (MF) (300 kHz to 3 MHz)
160 metres (1.8 - 2.0 MHz)

High Frequency (HF) (3.0 - 30.0 MHz)
80 metres (3.5 - 4.0 MHz)
60 metres
(five USB voice channels: 5.332, 5.348, 5.368, 5.373, 5.405 MHz)
40 metres (7.0 - 7.3 MHz)
30 metres (10.100 - 10.150 MHz)
20 metres (14.000 - 14.350 MHz)
17 metres (18.068 - 18.168 MHz)
15 metres (21.000 - 21.450 MHz)
12 metres (24.890 - 24.990 MHz)
10 metres (28.0 - 29.7 MHz)

Very High Frequency (VHF) (30 to 300 MHz)
6 metres (50 - 54 MHz)
2 metres (144 - 148 MHz)
1.25 metres (222 - 225 MHz)

Ultra High Frequency (UHF) (300 MHz to 3 GHz)
70 centimetres (420 - 450 MHz)
33 centimetres (902 - 928 MHz)

<table>
<tr><th>Commercial Radio</th><th>ISM
industrial-scientific-medical frequency band</th><th>Wireless Internet</th></tr>
<tr><td>88-108 MHZ</td><td>902-928 MHz,
2400-2483 MHz,
5725-5780 MHz
<table><tr><th>Description</th><th>Freq</th></tr><tr><td>Cordless Phone</td><td>43-50 MHz
900 MHz-2.4Ghz
DSS</td></tr></table></td><td>2400 - 2 483.5 MHz
2 layers</td></tr>
</table>

Bluetooth

2402 - 2480 MHz
with 79 1-MHz RF channels

Generally, small handhelds like the palm, and most new macintosh computers use "bluetooth" as a means of exchanging data within 30 feet. It enables users to connect a wide range of computing and telecommunications devices easily and simply, without the need to buy, carry, or connect cables.

It uses the 2.4 ghz spectrum to communicate a 1 megabit connection between 2 devices for both a voice channel and a 768k data channel The entire channel has a total capacity of 1 megabit per second (Mbps). Headers and handshaking information consume about 20 percent of this capacity.

In the United States and Europe,
the frequency range is 2,400 to 2,483.5 MHz,
with 79 1-MHz radio frequency (RF) channels.

In practice, the range is 2,402 MHz to 2,480 MHz.
In Japan, the frequency range is 2,472 to 2,497 MHz with 23 1-MHz RF channels.

A data channel hops randomly 1,600 times per second
between the 79 (or 23) RF channels.
Each channel is divided into time slots 625 microseconds long.
A piconet has a master and up to seven slaves.
The master transmits in even time slots, slaves in odd time slots.
Packets can be up to five time slots wide.
Data in a packet can be up to 2,745 bits in length

Television

VHF

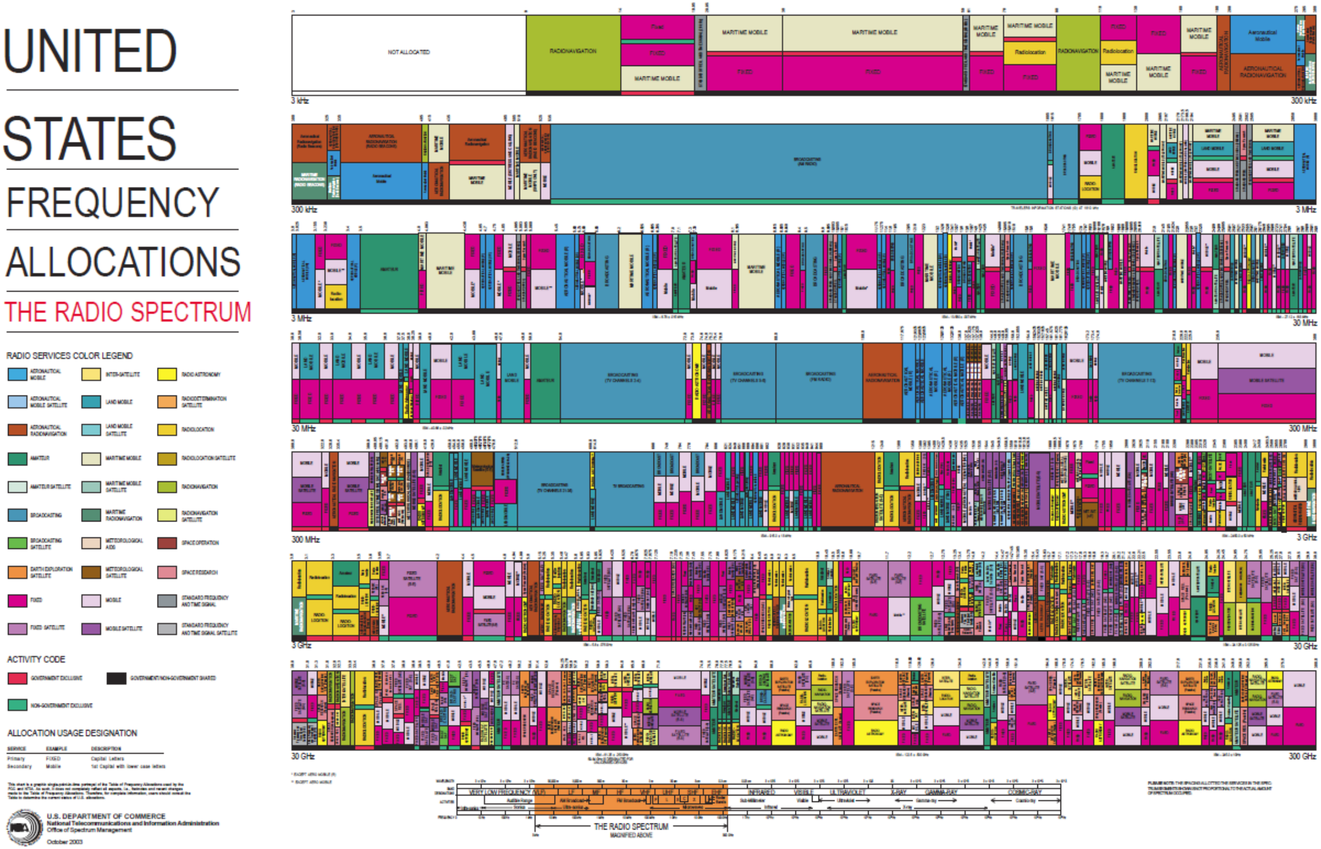
The general services in the VHF band are:
30-46 MHz: Licensed 2-way land mobile communication
30-88 MHz: Military VHF-FM, including SINCGARS
46-50 MHz: Cordless telephones, "49 MHz" FM walkie-talkies, and mixed 2-way mobile communication
50-54 MHz: Amateur radio "6-meter" band
54-72 MHz: TV channels 2, 3, and 4
72-76 MHz: Remote Control devices
76-88 MHz: TV channels 5 and 6
88-108 MHz: FM broadcasting (88-92 non-commercial, 92-108 commercial)
108-118 MHZ: Air navigation beacons VOR
108-132 MHz: Air Traffic Control (AM), 121.5 MHz is emergency frequency
132-144 MHZ: Auxiliary civil services,satellite, space research, and other miscellaneous services
144-148 MHz: Amateur "2-meter" band
148-174 MHz: "VHF Business Band", the new unlicensed Multi-Use Radio Service (MURS), and other 2-way land mobile, FM
156-174 MHz VHF Marine Radio FM
162.40-162.55: NOAA Weather Stations, FM
174-216 MHz: TV channels 7 through 13, and professional wireless microphones (low power, certain exact frequencies only)
216-222 MHz: mixed services
222-225 MHz: Amateur "1-1/4-meter" band
above 225 MHz: Federal services, including military aircraft radio (225-400 MHz) AM, including HAVEQUICK

UHF

brief summary of some UHF frequency usage:

300 - 420 MHz: government use, including meteorology
420 - 450 MHz: radiolocation and Amateur "70 cm" band
450 - 470 MHz: UHF business band, GMRS, and FRS 2-way "walkie-talkies"
470 - 512 MHz: TV channels 14-20, public safety
512 - 806 MHz: TV channels 21-69 (channels 53-69 to be auctioned)
806 - 824 MHz: pocket pagers and Nextel SMR band
824 - 849 MHz: cellular phones, A & B franchises, mobile phone
849 - 869 MHz: public safety 2-way (fire, police, ambulance)
869 - 894 MHz: cellular phones, A & B franchises, base station
902 - 928 MHz: ISM band: cordless phones and stereo, datalinks
928 - 960 MHz: mixed Studio-Transmitter Links, mobile 2-way, other
1240 - 1300 MHz: Amateur radio
1850 - 1910 MHz: PCS mobile phone - note below
1930 - 1990 MHz: PCS base stations - note below note: order is A,D,B,E,F,C blocks. A,B,C = 15 MHz; D,E,F = 5 MHz
2310 - 2360 MHz: Satellite radio Sirius and XM
2390 - 2450 MHz: Amateur radio, shared with below:
2400 - 2483.5 MHz: ISM, IEEE 802.11, 802.11b, 802.11g Wireless LAN
around 2450 MHz: Microwave oven

http://www.ntia.doc.gov/osmhome/allochrt.pdf



Basic Questions

- How to better use available spectrum?
  - Bluetooth uses Frequency Hopping over 80 channels
  - Wi-Fi splits into 2 to 5 channels (depending on country)
- How to optimally use the assigned channels?
  - FDM, TDM, CDM, SDM within channel
  - Frequency-Division Multiplexing further splits channel
  - Time-Division Multiplexing assigns valid time intervals to connections
  - Code-Division Multiplexing assigns chipping sequences
  - Space-Division Multiplexing uses directional waves to bypass others

Channel Usage

- Statistical usage rates
  - Historically, a particular connection is only active 10% of the time
  - Not true in modern networks, but still less than 100% utilization
- Priority usage, QoS
  - Some users and data in a particular frequency range are more important
  - Real time data vs delayed
  - In-order delivery (video?) vs reliable accuracy (file transfer?)

Change the Way

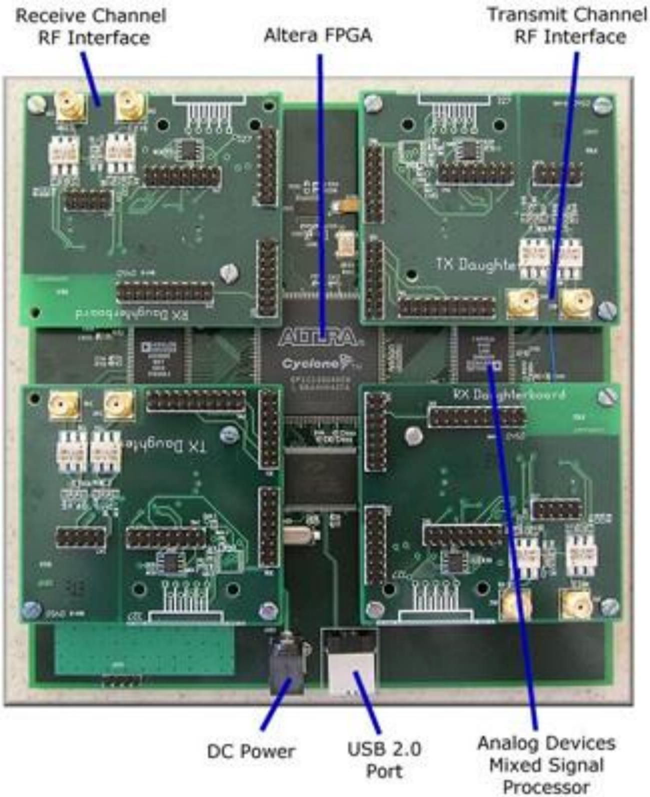
- Allow software to control network connections
    - (Instead of strict hardware, designed for singular device speed)
    - Slower individual speed, better network throughput
- SAN: Software Adaptable Network
- SDR: Software Defined Radio
- GNU Radio
    - Open source software radio package
- USRP: Universal Software Radio Peripheral
    - Hardware designed to use GNU Radio
    - Ettus research labs http://www.ettus.com

Cognitive Radio vs Cognitive Networks

- Radio concentrates on single-link range adaptation
    - Primary / Secondary user scheme
    - Sense patterns and usage rates in available channels
    - Secondary users transmit only on channels not used by Primary users and/or in same channels when Primary are idle
    - Tune: Frequency, Power, Modulation, etc…
    - SDR is a Radio-level concept
- Network level communicates a larger topology
    - Both wired and wireless
    - Network flow max, rather than local usage max
    - Top-level users and data, rather than just primary user(s)
    - Optimize and use Machine Learning across multiple OSI layers

Cognitive Radio

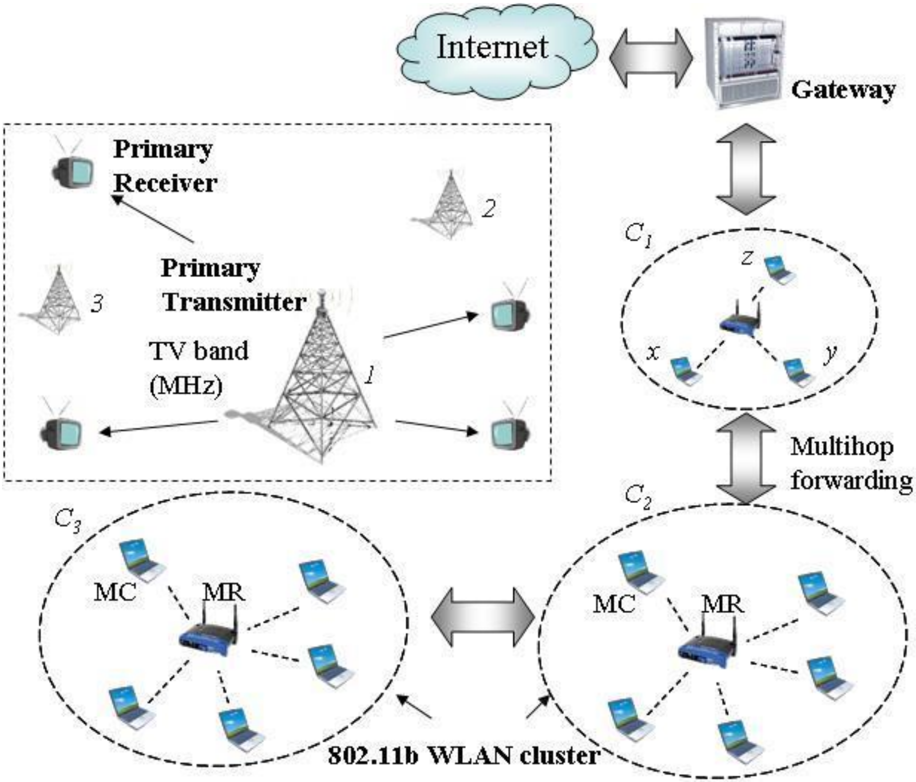
- Spectrum sensing
  - If a given channel or set of channels in use, use another one
  - Requires 2 devices to either:
    - Switch in same pattern at same time
    - Communicate from sensing device to other
    - One device able to listen / receive on multiple channels
  - Bluetooth does this automatically on an 80 channel band
  - SDR can define more channels of varying widths
- Channel sensing and prediction
  - Monitor a specific channel for general or primary user use
  - Predict lulls in activity, and use



http://www.ettus.com (Ettus USRP)

Cognitive Networks

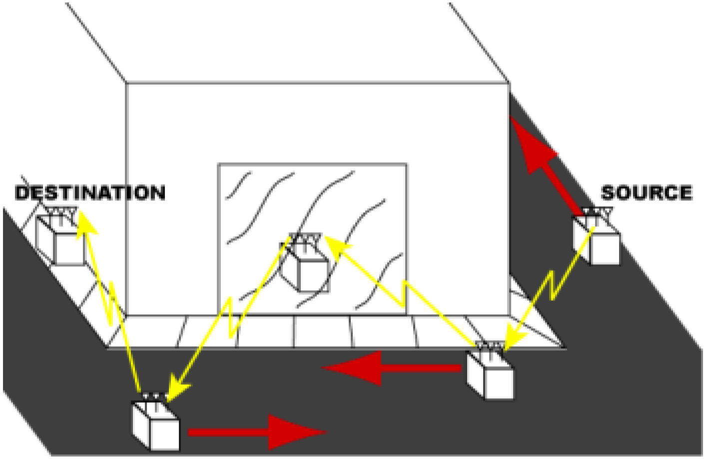
- Natural progression of flow requirements
    - Quality of Service
    - End-to-End
        - Reliable delivery
        - In-Order delivery
        - Best-Effort
- Maximize flow over end-to-end nodes on OSI Mac/Phy through Application
- Slow… multi-node graph processing
- Dynamic: QoS of Users and Applications change flow priorities



Cognitive Mesh (Chowdhury, GA Tech ECE)

Intelligent Adaptation

- Hidden terminals, multi-path, etc.
  - Detect, predict, and share information with neighboring nodes
  - Alter own broadcast patterns, even when no problem exists immediately
- Multiple primary users, hidden primary users
  - Attempt to guarantee priority data, at cost of secondary data
- Enact a virtual data structure across multiple OSI levels to model learned information (SDR, SAN)
- Machine Learning
  - With or Without neighbors participating, or blind primary users, use principles of Machine Learning to alter SDR/SAN.
  - Genetic Algorithms



Wave Interference :: Obstructed Path

Genetic Algorithms in Cognitive Radio

- Chromosomes defined over all available SDR aspects
- Target / Goal state / Fitness function optimizes:
    - maximum data flow, within the Constraints of Primary / Top-level users and applications
    - minimum spectral occupancy for other devices to use
- Small changes (mutations) and combinations (crossovers) in [Power / Frequency / Shape / Symbol Rate / Modulation] test against Fitness function.
- Optimize over multiple generations of testing

Table 7. Simulation Test Results

Radio Parameter	Weights			
	Minimize spectral occupancy	Maximize throughput	Interference avoidance	
	(a)	(b)	(c)	(d)
Power (dBm)	18	28	29	23
Frequency (MHz)	2440	2430	2436	2436
Symbol Rate (Msps)	1	18	3	8
PSF roll-off	0.05	0.33	0.04	0.04
PSF order	46	20	18	13
Modulation, type	PSK	QAM	PSK	QAM
Modulation, M	2	16	4	8
BER	0	0	0	0.12
Data Rate (Mbps)	1	72	6	24

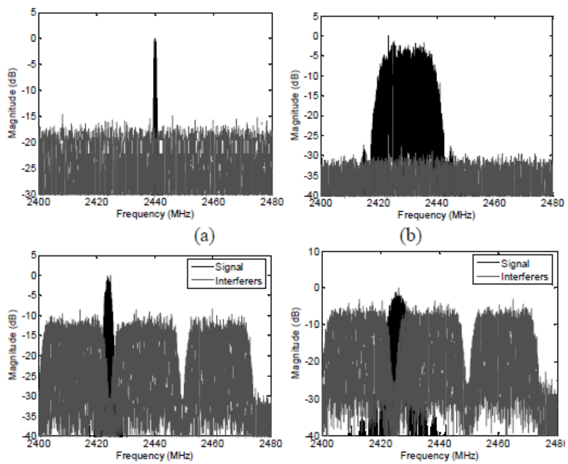


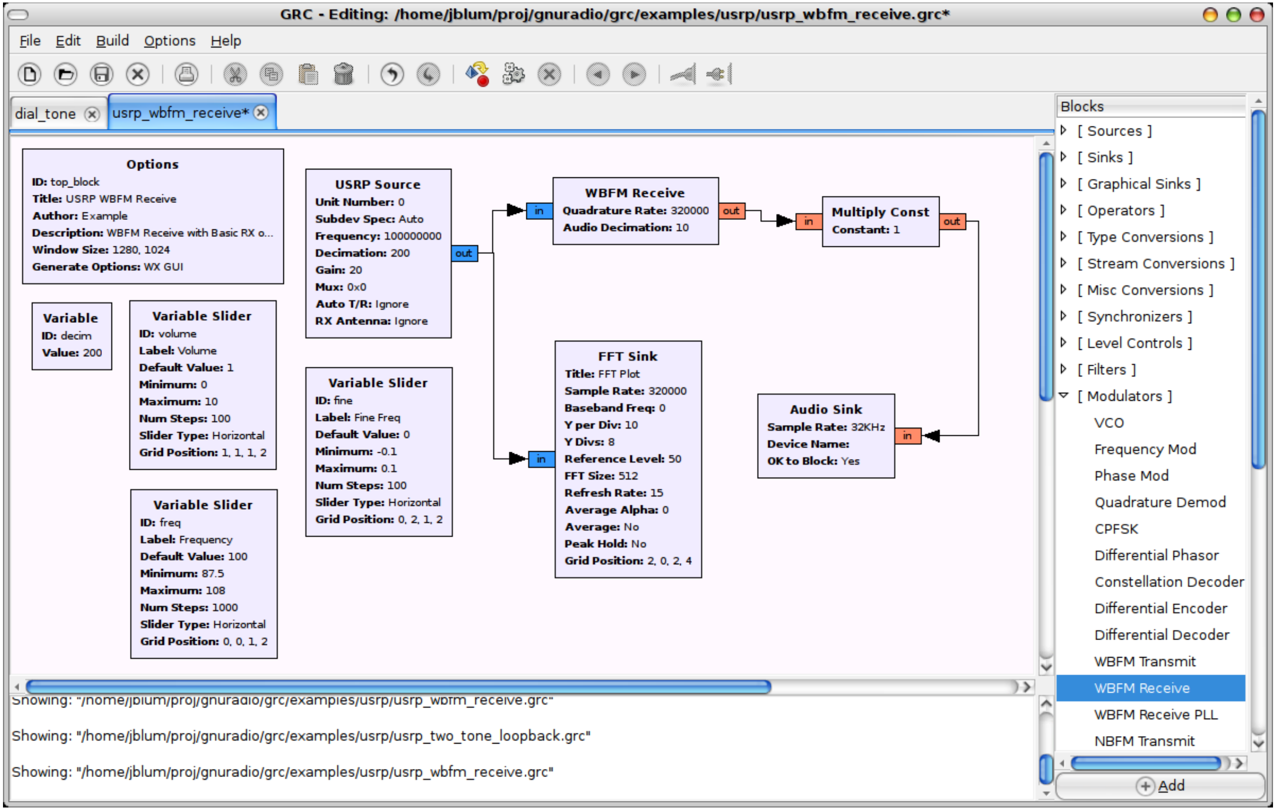
Fig. 3. Spectrum Plots for scenarios of Table 6.

Table 6. Simulation Test Conditions

Functions	Weights		
	Minimize spectral occupancy	Maximize throughput	Interference avoidance
BER	255	100	200
BW	255	10	255
Spectral Efficiency	100	200	200
Power	225	10	200
Data Rate	100	255	100
Interference	0	0	255

Table 1. WSGA Genetic Parameters

Parameter	Value
Crossover Rate	90 %
Mutation Rate	5 %
Population Size	30
Replacement Size	20
Max Generations	50



GRC example from http://www.joshknows.com