Prepared for the South African IEEE Joint AP/MTT/EMC Chapter Conference 2016, Stellenbosch, South Africa, July 28 – 29, 2016 (http://www.ee.sun.ac.za/saieee2016/)

Work in television white spaces (TVWS) and dynamic spectrum and a bit on antennas

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CSIR Meraka Institute

2016-07-29

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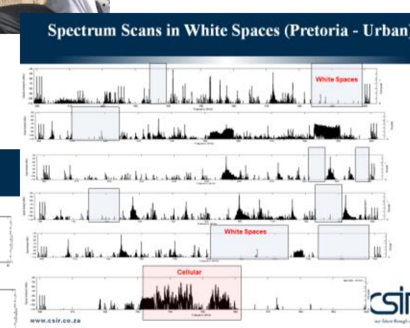
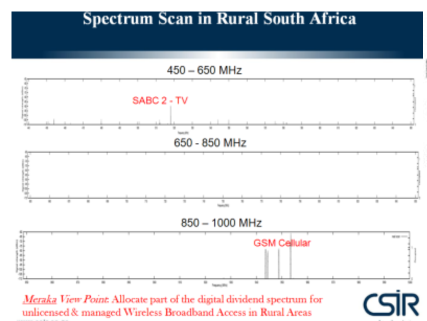
Content

- Introduction
- Networked antenna
- Television white spaces (TVWS), dynamic spectrum management

Who we are – what we do

- Broadband connectivity for rural areas
  - Unreliable power
  - Need for multimedia, thus high bandwidth
  - *Meraka connectivity devices installed in over 200 rural schools*
- Smart antennas & Energy efficiency
  - Distributed wireless comm. protocols
  - 10x faster
- Consulting / Auditing
  - Wireless networking for mining
- Sensor networks
  - Localization, Smart applications
  - Challenging applications (e.g. deep mining, robotics)
  - Water & Container monitoring
- Cognitive radio (CR) research
  - TVWS trials, extensive lab measurements
  - Spectrum measurements campaigns
  - First research session on CR in Africa in conference Africon 2011
  - One of the first large trials of white space devices in Africa 2012/13, with Google, Microsoft and others





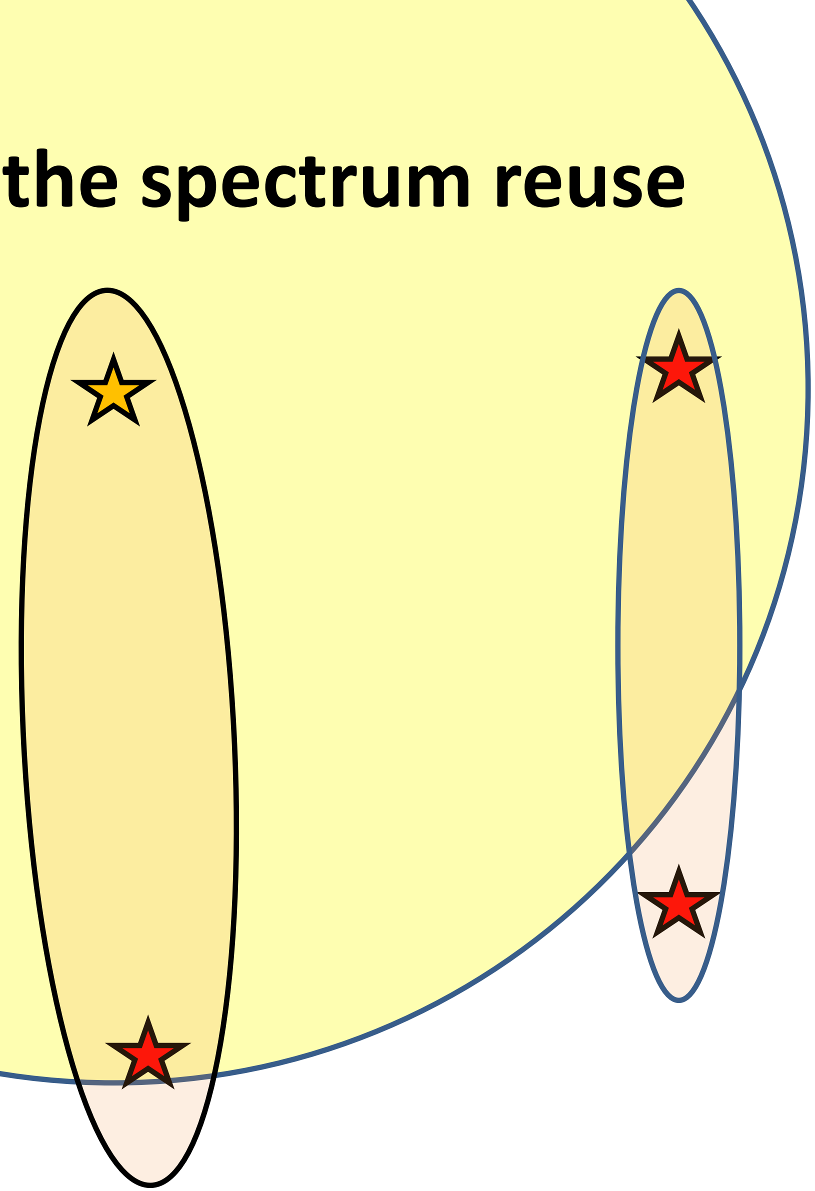
Networked antenna

- Goal: Faster, more robust networks

A note on spatial aspect of the spectrum reuse

- In a wireless network shown here, depending on antenna used …
  - Omni ➔ one TX at a time
  - Directional ➔ parallel TXs

- Spectral efficiency
  - Depends on the topology of network
  - Depends on protocols supporting the intelligent control of beamforming / switching and power control
  - Much improvement (5-100x) can be achieved
  - **Capacity(link) ~ (B*log$_2$(1+SNR))**
  - **Capacity(mesh) ~ (1 / Beamwidth)**



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Throughput and delay in network vs ***abilities*** of smart antenna – how much?

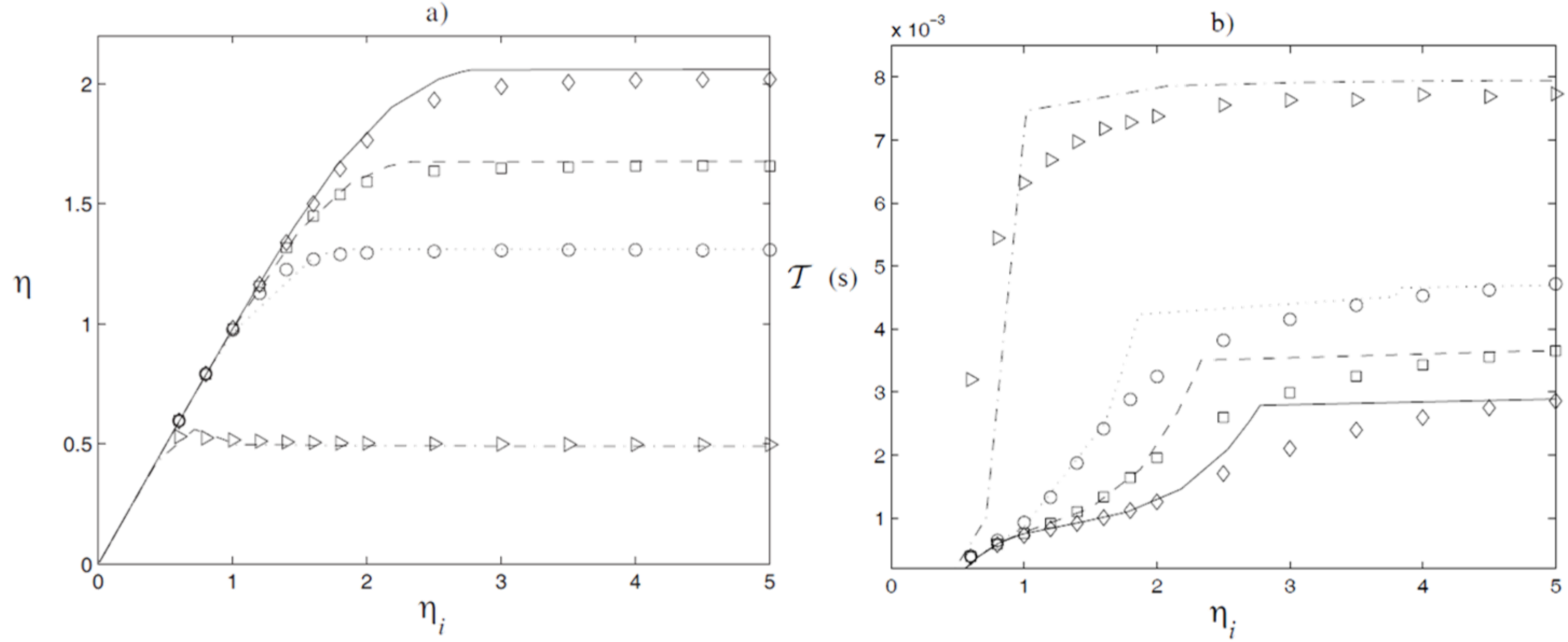


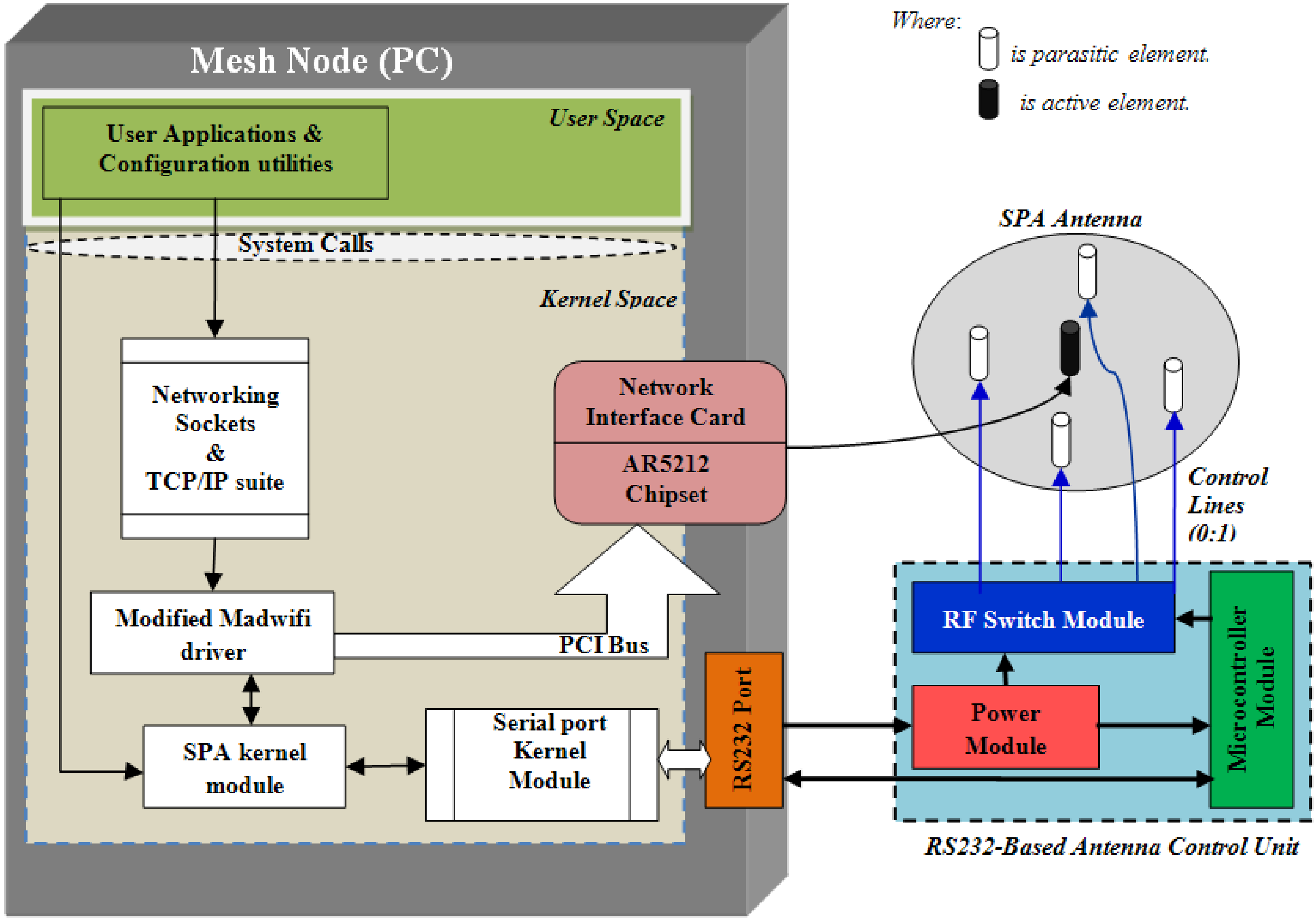
Fig. 5. Aggregate throughput (a) and average packet delay (b) as a function of the net offered load for $R = R_c$, $\hat{\sigma}_\varphi = 0^o$, $n = n_2 = 25$ and m=m'=6.
—— AA (Analysis) – – – – DA (Analysis) ········ SBA (Analysis) –·–·– 802.11a (Analysis)
◇ AA (Simulation) □ DA (Simulation) ○ SBA (Simulation) ▷ 802.11a (Simulation)

[R.R. Choudhury, X. Yang, R. Ramanathan, and N.H. Vaidya, “On Designing MAC Protocols for Wireless Networks Using Directional Antennas”, IEEE Trans. on MOBILE COMPUTING, Vol. 5, No. 5, May 2006, pp. 477-491]

10x throughput improvement observed in a static scenario in wireless mesh network, with presence of an interferer [Lysko, AA, Johnson, DL and Mofolo, MOR. Significant performance improvement obtained in a wireless mesh network using a beamswitching antenna. SATNAC 2012, South Africa, 2-5 Sep 2012]

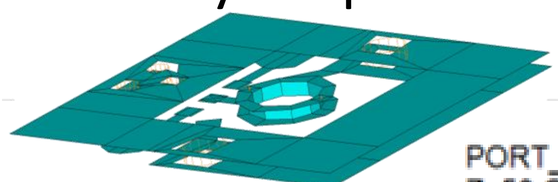
System Development - Overview

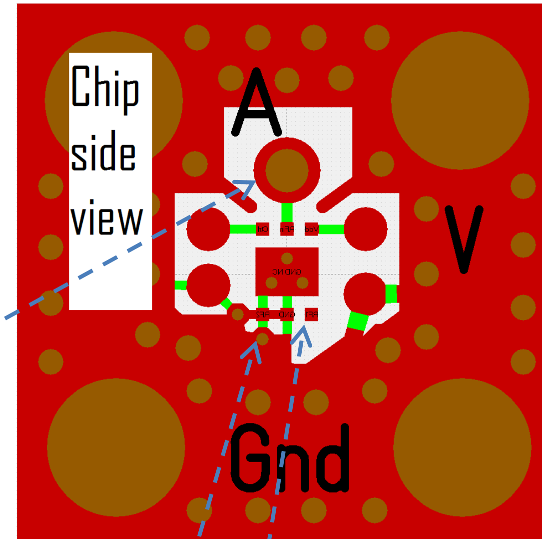
- Node / PC
  - Software, driver
- Interface
- Antenna controller
  - hardware,
  - software
- Antenna
- Adaptable to other embedded systems



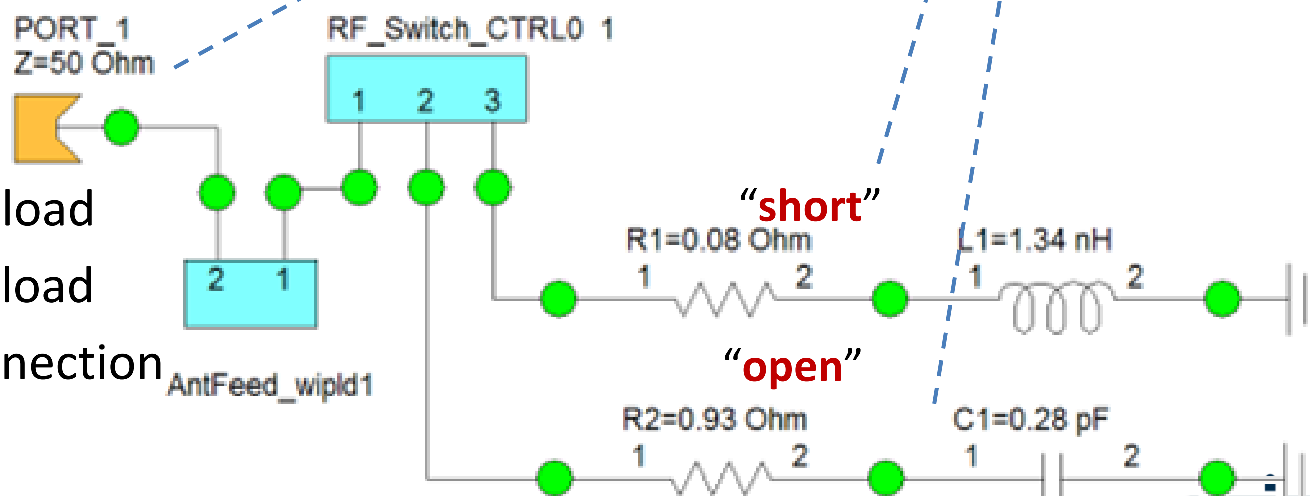
Antenna and its design

- 2.4 GHz band
- 4 parasitic elements
  - Terminated into SPDT RF switches
    - open/short
- Analyzed parasitics numerically first





- 3 unknowns:
  - Open circuit load
  - Short circuit load
  - Antenna connection



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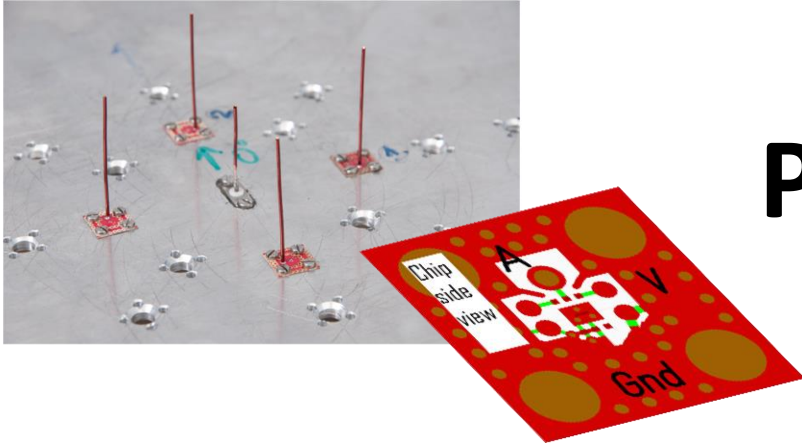


Prototype 1 summary

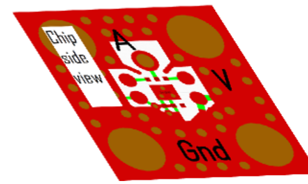
- **Achieved:**
  - **10x better throughput measured in wireless mesh network in presence of interference**
  - **Very low power consumption <1.5mW**

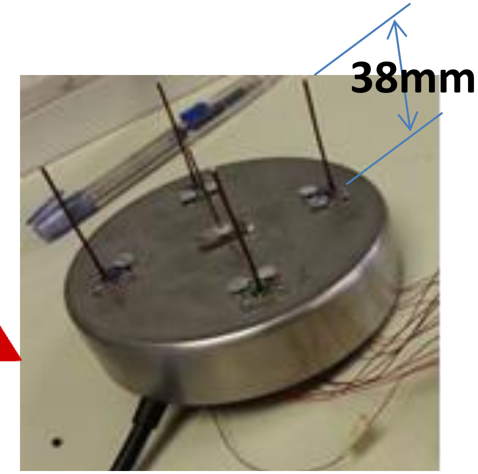
Test case	Throughput, Mbps	Std deviation, %
Omnidirectional pattern	0.201	18
Directional pattern towards interferer	0.171	34
Directional pattern towards the desired node	**2.04**	**2**

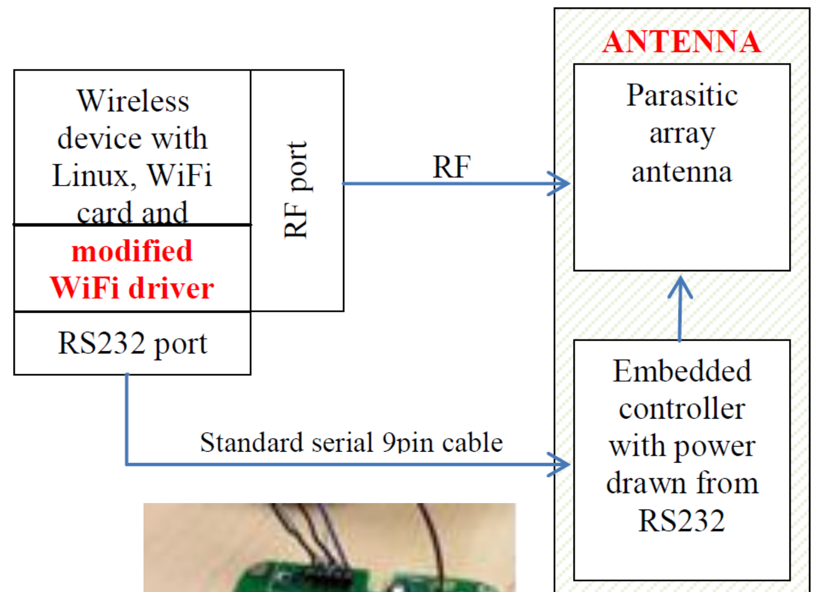
Lysko, Johnson, & Mofolo, (2012). Significant performance improvement obtained in a wireless mesh network using a beamswitching antenna. SATNAC 2012, 2-5 September 2012. Fancourt, South Africa.
Lysko & Johnson (2008). A study of propagation effects in a wireless test bed. *WSEAS Transactions on Communications*, *7*(8).
Johnson & Lysko (2008). Comparison of MANET routing protocols using a scaled indoor wireless grid. Mobile Networks and Applications, 13(1-2).

Current prototype, v2

- Includes
  - Prototype of antenna
    - Power cons. <1.5mW
  - Modified mesh WiFi driver
    - Able to switch beams automatically, per packet







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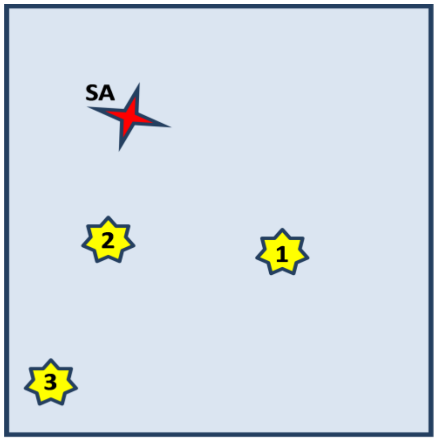
Antenna/RF performances achieved

Mode (sample code value*)	Max gain*, dBi	HPWB*, deg	Maximum gain span*, dB	Worst RL, dB	Impedance 10-dB bandwidth, MHz
Omnidirectional (1111)	0.1	360	0.4	-20.4	> 500 MHz
Wide beam (0111)	3.3	170	n/a	-16.3	> 450 MHz
Narrow beam (0011)	5.1	106	n/a	-12.4	>350 MHz
Required		*~90*		*-10*	*100 MHz*

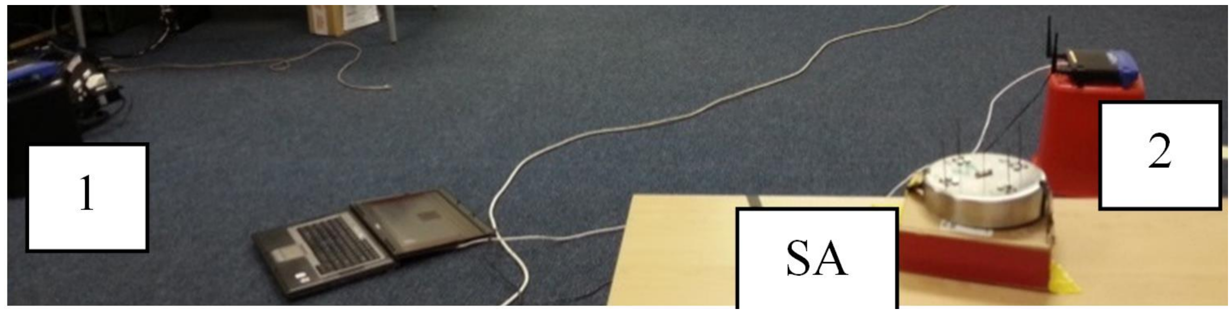
* 2^4=16 combinations for four SPDT switches, giving four unique types of patterns

Performance: Test environment

Location of nodes
In the room



Picture of some of the nodes in the room
("SA" refers to the beamswitching antenna)



- 6.7 m × 6 m test room

- Network latency was estimated using Linux command *ping*
- Network throughput was estimated using Linux command *iperf* (which sent a burst of traffic from one node to another and measured the total number of bytes sent over the defined period of time, thus deriving the throughput in MB/s).
- Received signal strength indicator (RSSI) values were recorded for the different configurations.

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Mesh network level performance

- The tests show that the system achieved
  - up to **3.9× throughput speedup**, and
  - up to **2× reduction in the latency**, over a traditional monopole antenna with equal gain.

- The operation of the failover feature for a failure of a node in a mesh network was tested:
  - The tests showed the successful switch to a live node within 8 seconds.

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Television white spaces (TVWS), dynamic spectrum management

Current spectrum management:

- Inflexible
- long term / large area assignments and allocations

Long term goals:

- Making more spectrum available
    - at more places
    - at lower costs
    - faster
- Better protection for existing users

Approach:

- automate spectrum management

Why do TVWS in Africa (incl. South Africa)

- **Need for communications**
  - e.g. South African government targets:
    - 100% broadband by 2020, with tough specifications, e.g. each school needs >= 10Mbps
    - [National Broadband Policy "South Africa Connect", 2014]

… whilst …

  - Large geographic area, incl. large rural areas, some vegitation
    - TVWS offers best coverage and penetrates well through vegetation and walls
  - Significant population in rural areas

Africa uniquely positioned

Western Europe 15% rural

USA 17% rural

Sub Saharan Africa 63% rural
Almost entire UHF TV band open

Strongest case for use of WS
For innovative broadband solutions

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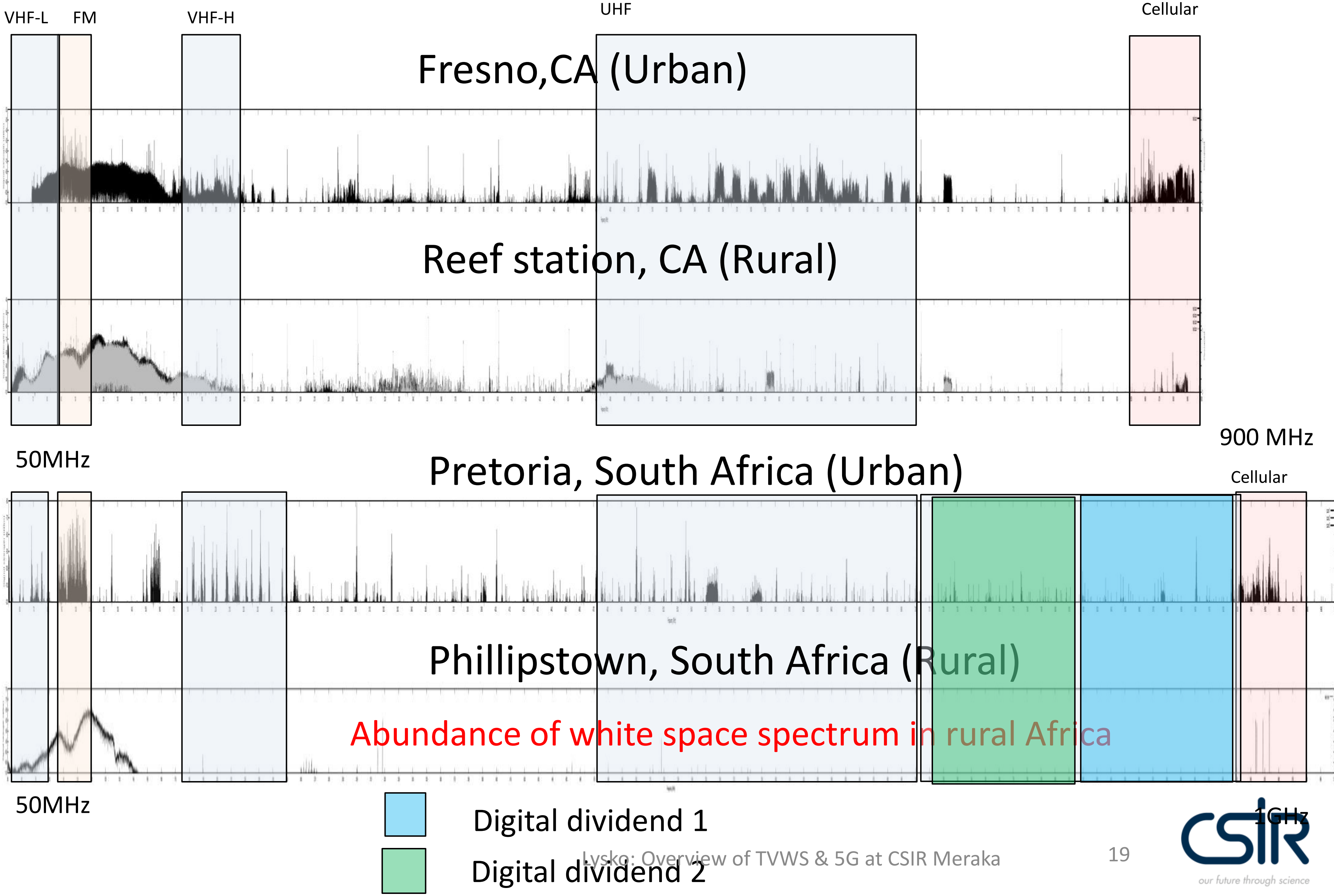
White space spectrum availability

Spectrum availability – how much white space?



Summary of activities

- Smart / small / energy efficient antennas
  - Antennas (parasitic array with <1.5mW power cons.!), WiFi driver to control it
- TVWS trials / tests / scans
  - Cape Town (2013), Limpopo (2014), Ghana (2015), Pretoria & Durban & Cape Town (2016)
- Geolocation spectrum database (GLSD)
  - Supports South Africa, and other countries, e.g. Ghana, and soon Botswana
  - Certified by Ofcom, UK
  - Cooperation with for TVWS OEM on PAWS support
- TVWS devices
  - Own TVWS+WiFi device (21Mbps in TVWS, PAWS, spectrum scanning etc.)
- Convergence work
  - DVB-T2 as data downlink in ***L***-band
  - Applying TVWS techniques to solve LTE in Digital dividend bands
- Policy work
  - Support local regulator ICASA, e.g. support in
    - Discussion Paper on the Draft Framework for Dynamic and Opportunistic Spectrum Management, published in the Government Gazette 39302, 2015
    - Findings Document on the Framework for Dynamic and Opportunistic Spectrum Management, published in the Government Gazette 40078, 2016

https://www.icasa.org.za/LegislationRegulations/EngineeringTechnology/RadioFrequencySpectrumManagement/NationalFrequencyPlan/tabid/655/ctl/ItemDetails/mid/2506/ItemID/10541/Default.aspx , http://www.gov.za/sites/www.gov.za/files/40078_gen350.pdf

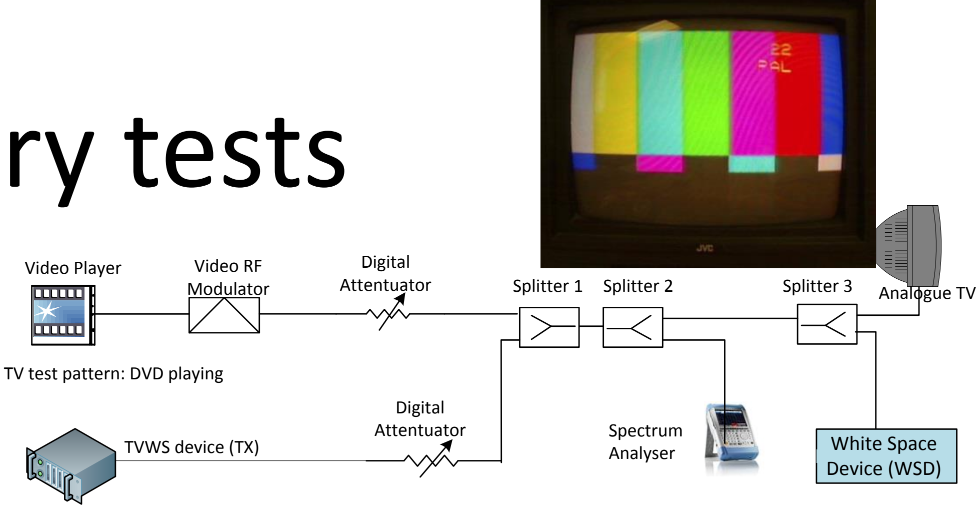
Trials and tests

	Cape Town	Limpopo	Ghana
Year	2013	2014	2015
Network type	P2MP	P2P + hops	P2MP
Served people	9500	5500	9700
Network size	10 schools in 30 km2	5 schools in 70 km2	7 schools in 40 km2
GLSD (to plan)	Google	CSIR	CSIR
Antenna gain	**10-11** dBi	**6**/11 dBi	?
Longest link	6.5 km	8 km	6.7 km
Down/Up-Link	**12**/6 Mbps	**5** Mbps	?
Latency	120 ms	4-10 ms	?
Highlight	Adjacent channels used	Users never used Internet before	Assisting a foreign state

~20,000 users!

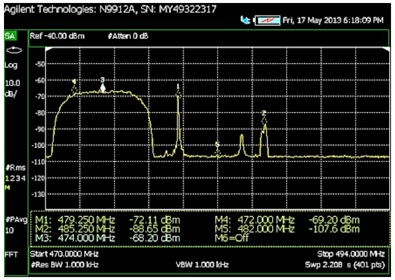
- Lysko, A.A. et al., "First Large TV White Spaces Trial in South Africa: A Brief Overview," ICUMT 2014, Russia
- Masonta, M.T.; Kola, L.M. ; Lysko, A.A. ; Pieterse, L. ; Velempini, M., "Network performance analysis of the Limpopo TV white space (TVWS) trial network," IEEE AFRICON 2015, Sep 2015 – *BEST PAPER AWARD*

Trials & Laboratory tests



<u>Typical set of tests we perform</u>:

- Laboratory testing
  - Power, Spectrum mask, Bandwidth
  - EMC/EMI
  - Dynamic behaviour (boot up, channel switch, control, …)
  - Protection ratio determination (PAL-I, DVB-T2)
  - Network performance (throughput, latency)
  - etc.: Device dependent (P2P vs P2MP, interference, MIMO channel dis-balance, …)



- Radio planning of TVWS network
- Pre-trial spectrum scans
- Spectrum and network performance measurements during trial

http://www.tenet.ac.za/tvws

http://www.tenet.ac.za/tvws/cape-town-tv-white-spaces-trial-field-measurements-report-1

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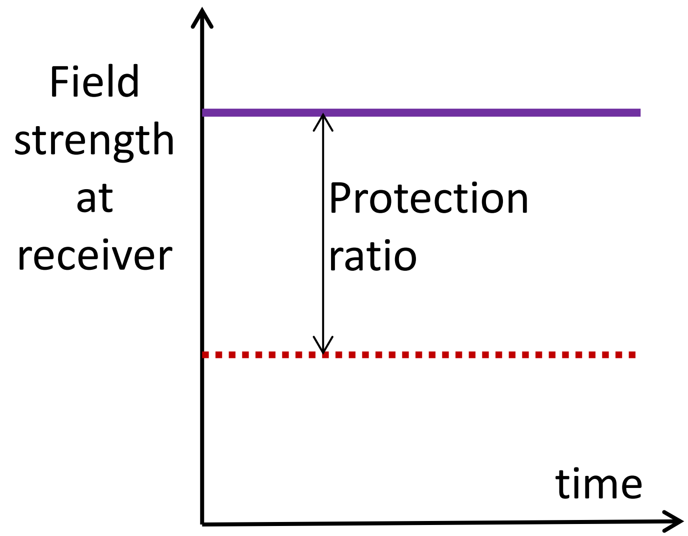
6: Protection ratio (PR) definition

- Need to protect – How?
- Limit emissions!
- ***ITU-R Rec. BT.655-6:*** "The RF ***Protection ratio*** is the minimum value of wanted-to-unwanted signal ratio, usually expressed in decibels at the receiver input, determined under specified conditions such that a specific reception quality is achieved at the receiver output".



In TVWS case:

- "wanted" = TV signal from broadcasting
- "unwanted" = potential interferer, i.e. TVWS

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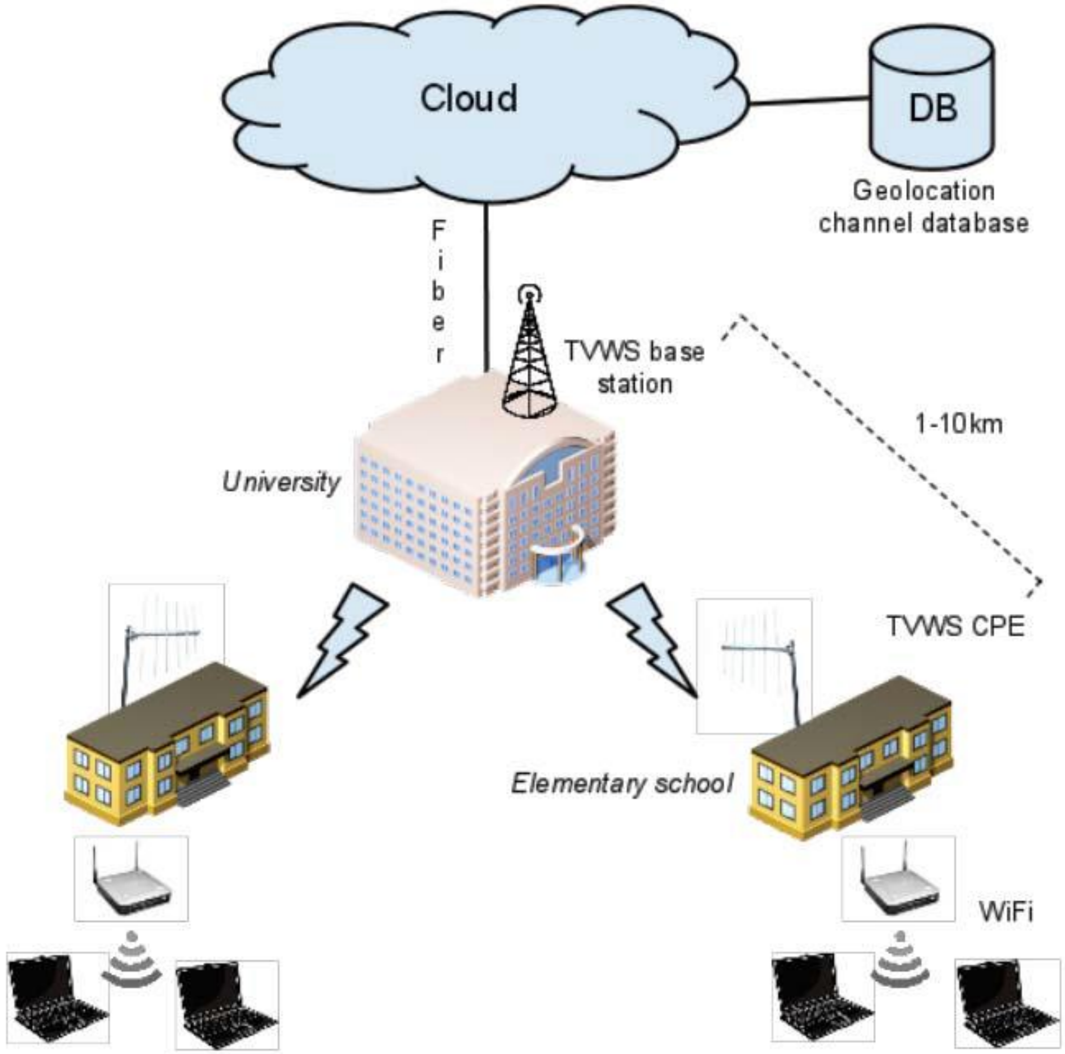
Principles of non-interfering operation of devices in under-used spectrum



1. DB has info about location of TV transmitters and topology of the area, and so can do propagation predictions
2. DB then uses these predictions to estimate whether TV signal is too weak for TV reception and can thus be reused locally
3. base station (BS) obtains this info from DB
4. Terminals obtain this info from BS, by listening only
5. Terminals and BS only transmit when and where allowed by DB

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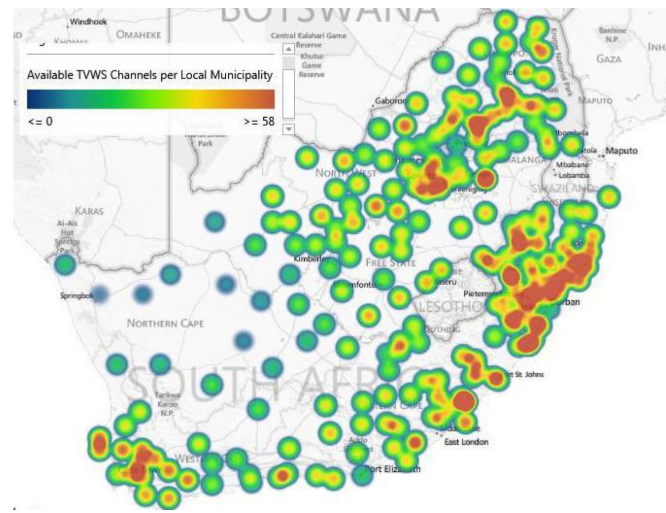
Geolocation spectrum database (GLSD)

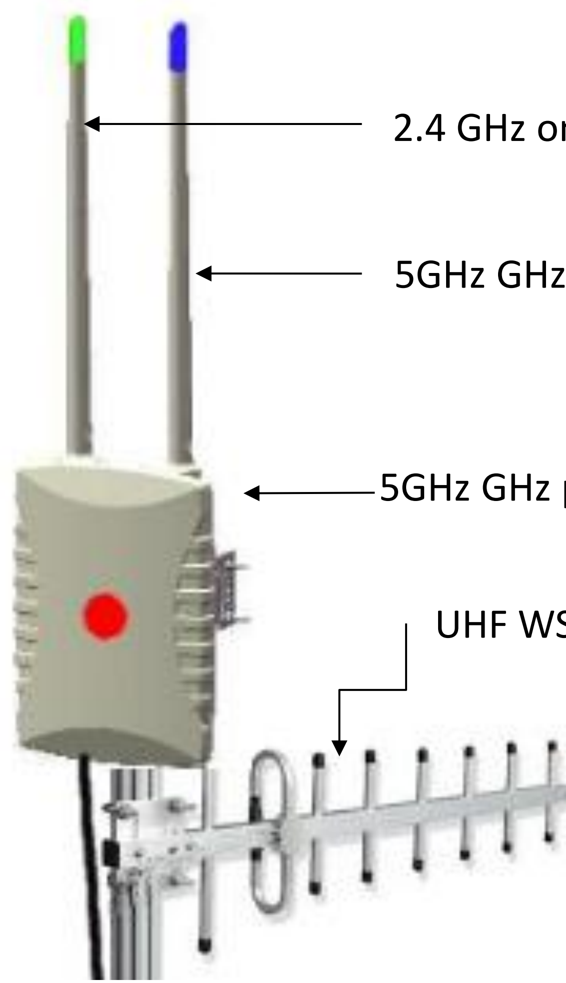
- Developed in-house by CSIR
- Supports IETF Protocol to Access White Space (PAWS), ITU Rec. P.1546-4/5, P452-14/15, ITWOM, modified R-6602/FCC curves, protection ratios for ITU Region 1, etc.
- Certified by Ofcom, UK to operate in UK on commercial basis
- A patent



http://whitespaces.meraka.csir.co.za/

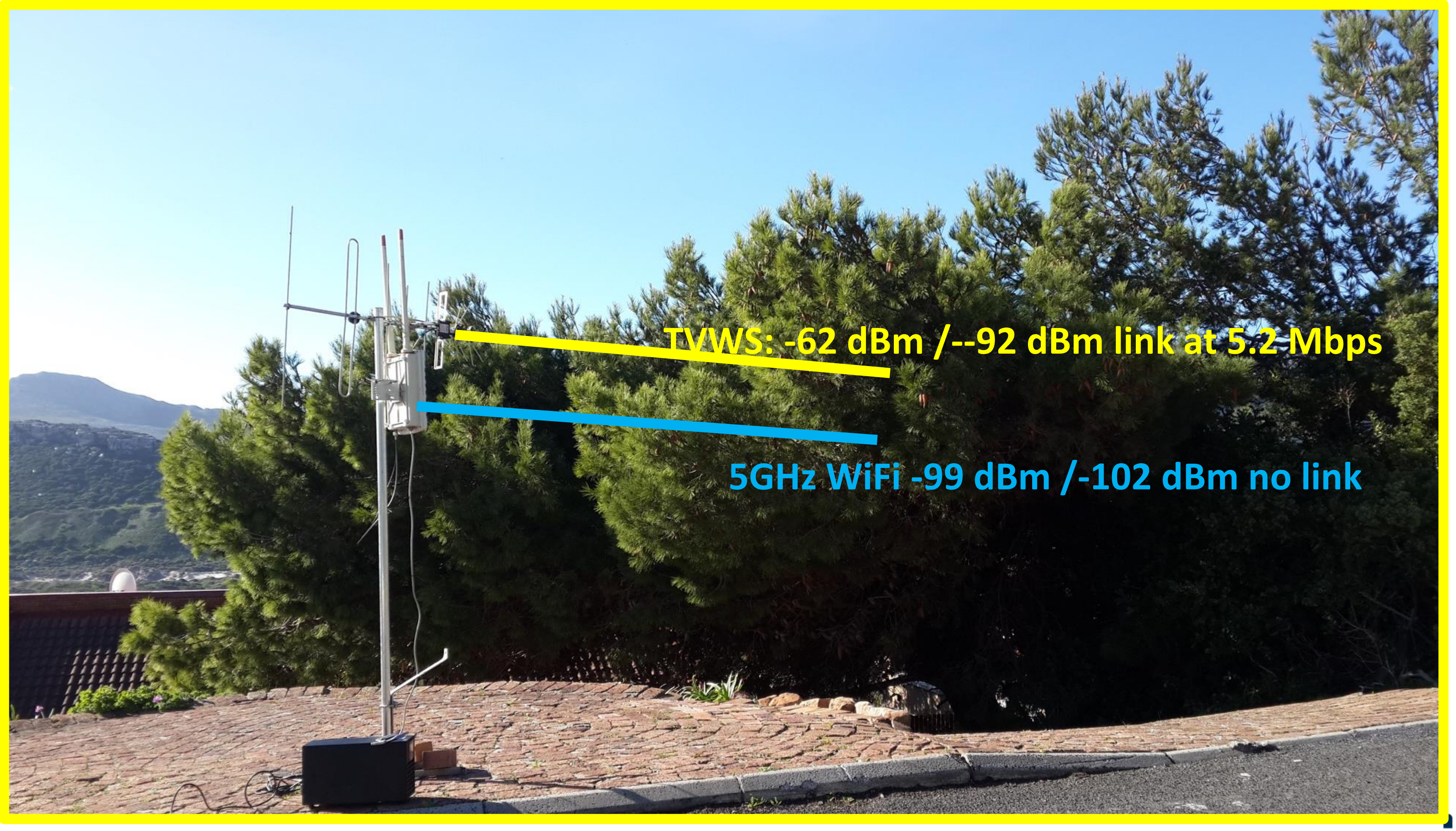
CSIR White Space Mesh Node(WSMN)

- Features
  - TVWS **and** WiFi
  - **runs mesh on TVWS and WiFi**
  - PAWS access to GLSD
  - Embedded Spectrum analyzer
  - Max speed: 21 Mbps on TVWS and 23 Mbps on 5GHz WiFi

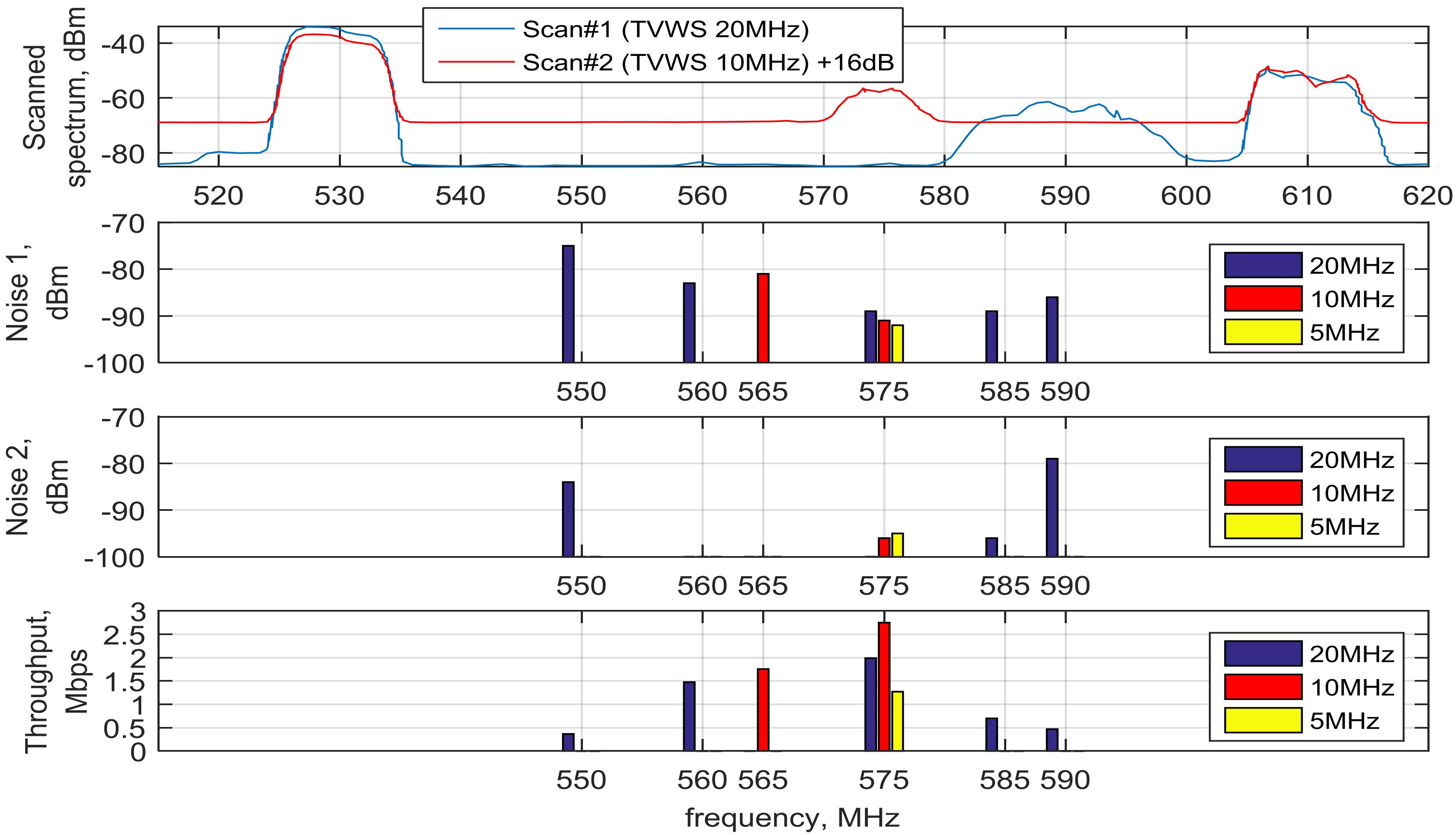


Why consider WiFi? …

TVWS vs WiFi: battle 3km **NLOS**



Effects of channel width & broadcasting



Observations for TVWS device based on WiFi:

1. Drastic reduction of throughput from being too close to a TV channel
2. Lowering channel bandwidth may increase the throughput!

Pushing TVWS boundaries … (*preliminary results*)

- CSIR ran tests of new high speed TVWS devices:

REFERENCE:

UDP throughput tests in London by NICT, Japan in July 2014:

- 45 Mbps over 3.7 km in 40MHz
  - London, using LTE equipment

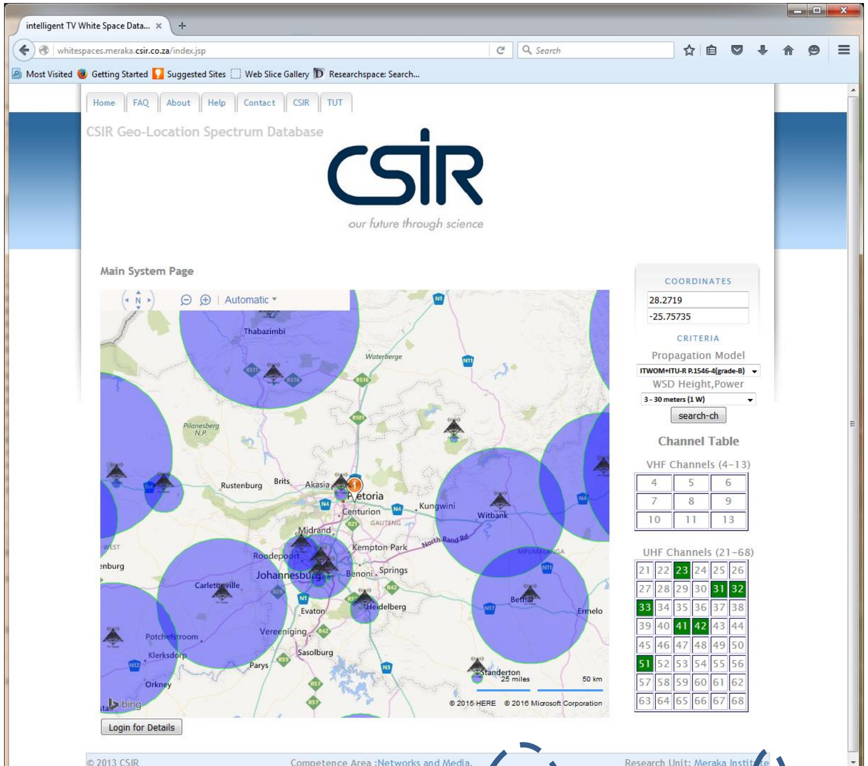
http://www.nict.go.jp/en/press/2014/07/24-1.html

CSIR:

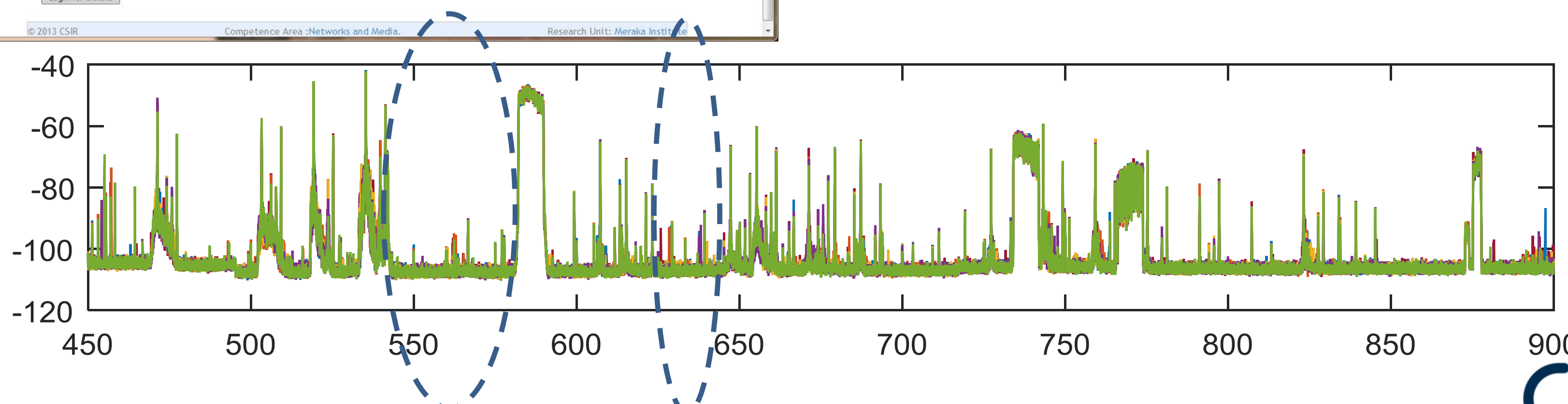
TCP throughput tests in Pretoria in January 2016

- 89 Mbps (duplex 125 Mbps), 2.3ms
  - over 71 m, in 20 MHz, through a tree
- 54 Mbps over 4 km in 14 MHz, 2.6ms
- Current challenge: 10MHz guard band not enough, likely due to the WiFi-like spectrum mask

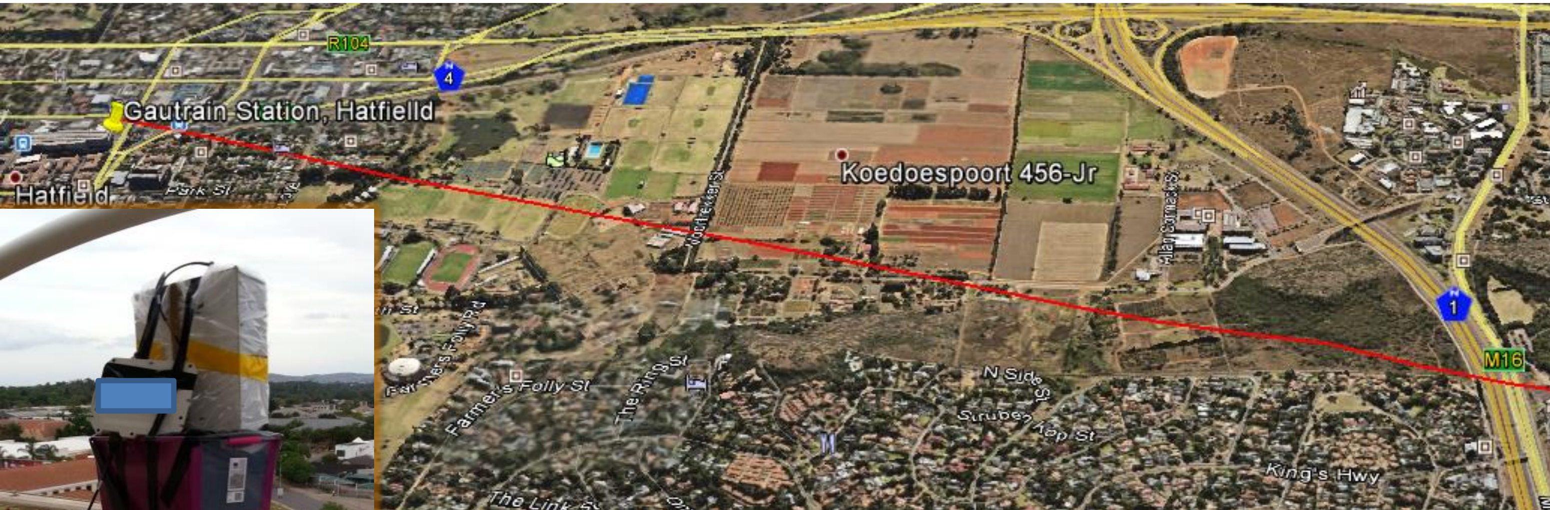
Tests in Pretoria: Finding spectrum



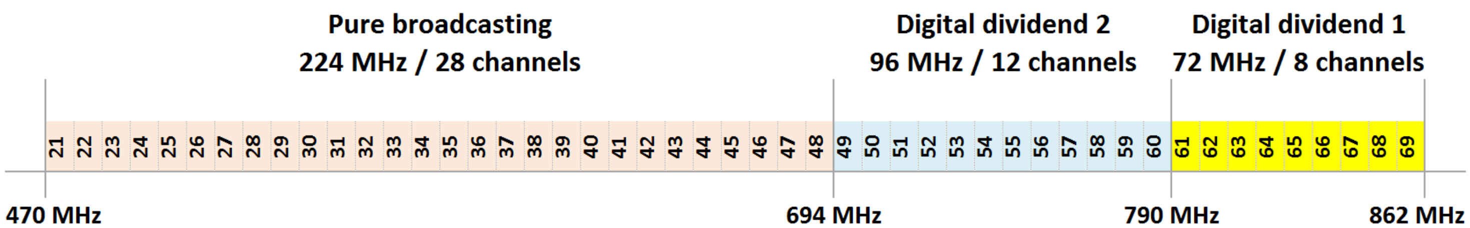
- Used:
  1. CSIR GLSD
  2. Spectrum scan
- Found available channels:
  - ➢23, **31-33**, 41-42,51



54 Mbps: 4 km TVWS link in Pretoria



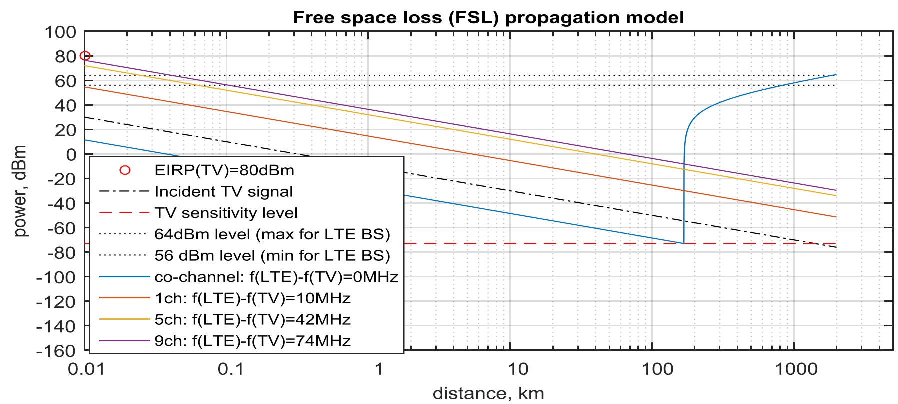
R&D: LTE in Digital Dividend bands in RSA

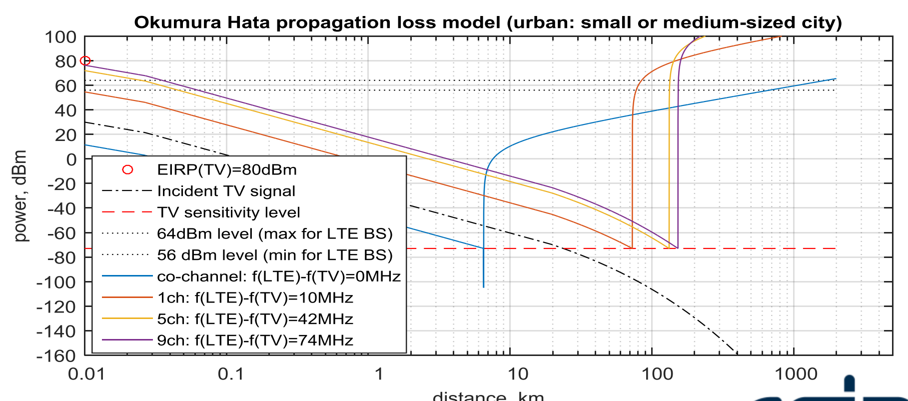


- There is a need to start introducing IMT (LTE) in in digital dividend (DD) bands
- Challenge: there is still TV broadcasting in those bands

➔ Compatibility studies

- *Results for DVB-T2 vs LTE shown→*
- Intermediate outcome
  - TV towers = good location for LTE BSs
  - Filtering may help to lower distances





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Recent R&D in TVWS vs WiFi

- Recent LOS/NLOS field tests in Pretoria and Cape Town show
  - "up/down-converted WiFi" TVWS devices struggle to achieve full capacity in scarcity of spectrum / presence of strong TV broadcasting
  - a need for stronger filtering, e.g. by frequency & angle-tunable antenna arrays
  - a need to select between TVWS and WiFi wisely
  - CSIR develops on existing high performance WiFi node to fully support and automatically switch between WiFi and TVWS (over a mesh netw.)
- Recent scans in Durban and Cape Town show
  - outdated TV broadcasting information may lead to erroneous channel availability
  - a need to monitor spectrum, identify actual spectrum usage as well as location and source of new transmitters, and inform spectrum regulator and update GLSD records, accordingly
    - a need for interfaces and intelligent and automatic information processing
  - a need for government policy set requirements for synchronising spectrum allocation and actual usage records

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Progress with regulations

4 No. 39534 GOVERNMENT GAZETTE, 17 DECEMBER 2015

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INDEPENDENT COMMUNICATIONS AUTHORITY OF SOUTH AFRICA

NOTICE 1221 OF 2015

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PURSUANT TO SECTION 4B OF THE INDEPENDENT COMMUNICATIONS AUTHORITY OF SOUTH AFRICA ACT 2006, (ACT NO. 3 OF 2006)

HEREBY ISSUES A NOTICE REGARDING AN EXTENSION OF THE CLOSING DATE FOR WRITTEN REPRESENTATIONS ON THE DISCUSSION PAPER ON THE DRAFT FRAMEWORK FOR DYNAMIC AND OPPORTUNISTIC SPECTRUM MANAGEMENT 2015

1. The Independent Communications Authority of South Africa ("the Authority"), on the 19th

4 No. 40078 GOVERNMENT GAZETTE, 17 JUNE 2016

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INDEPENDENT COMMUNICATIONS AUTHORITY OF SOUTH AFRICA

NOTICE 350 OF 2016

INDEPENDENT COMMUNICATIONS AUTHORITY OF SOUTH AFRICA

ICASA

FINDINGS DOCUMENT ON THE FRAMEWORK FOR DYNAMIC AND OPPORTUNISTIC SPECTRUM MANAGEMENT

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Highlights

- *First in Africa*: organized an African research forum on Cognitive Radio in the conference IEEE Africon'11
  - Two papers received 2 (out of 5) conference prizes
- *First in the world*: Tygerberg/Cape Town trial used for TVWS channels adjacent to operational TV broadcasting (PAL and DVB-T2), with no interference since 2013
  - FCC refers to Cape Town trial in document FCC 14-144 in 2014
- *Book published*: "White Space Communication: Advances, Developments and Engineering Challenges", Eds: Mishra & Johnson, Springer, 2015
- *Best paper award* at IEEE Africon 2015, for the paper "Network Performance Analysis of the Limpopo TV White Space (TVWS) Trial Network"
- *Latest testing snapshot on TVWS link testing*: 54 Mbps median TCP throughput over 4 km, 2016
- *Fully operational CSIR GLSD*, now certified by Ofcom, UK, one of about just a dozen in the world

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Summary / Next steps

- Extensive experience in trialling TVWS (3+ large trials)
- In-house developed geospatial spectrum database (GLSD) for UK, South Africa, Botswana and more
- Support TVWS OEM (e.g. implementation of PAWS to access GLSD)
- In-house development of TVWS devices
- Delivering quality, able of “world first/fastest”

<u>Next steps</u>

- More testing (incl. technology comparison, NLOS, filtering etc.)
- Channel allocation, incl. TVWS ad-hoc / mesh networks
- Keeping white space networks alive, when no access to GLSD
- Extension of Cape Town trial to cover 30kmX20km (from 30km2)
- GLSD plus Spectrum manager for 4G/5G
- Continuing and extending Policy work

THANK YOU

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IEEE Distinguished Lecturership programme (1)

- Can invite Distinguished speakers
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- IEEE AP, MTT & EMC Societies have these programs with 3-8 speakers available in each
  - other Societies have their own

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Using Model-Based Parameter Estimation to Increase the Efficiency and Effectiveness of Computational Electromagnetics
Abstract

Science began, and largely remains, an activity of making observations and/or collecting data about various phenomena in which patterns may be perceived and for which a theoretical explanation is sought in the form of mathematical prescriptions. These prescriptions may be non-parametric, first-principles generating models (GMs), such as Maxwell's equations, that represent fundamental, irreducible descriptions of the physical basis for the associated phenomena. In a similar fashion, parametric fitting models (FMs) might be available to provide a reduced-order description of various aspects of the GM or observables that are derived from it. The purpose of this lecture is to summarize the development and application of exponential series and pole series as FMs in electromagnetics. The specific approaches described here, while known by various names, incorporate a common underlying procedure that is called model-based parameter estimation (MBPE).

More

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Advanced Antenna Systems for Satellite Communication Payloads
Abstract

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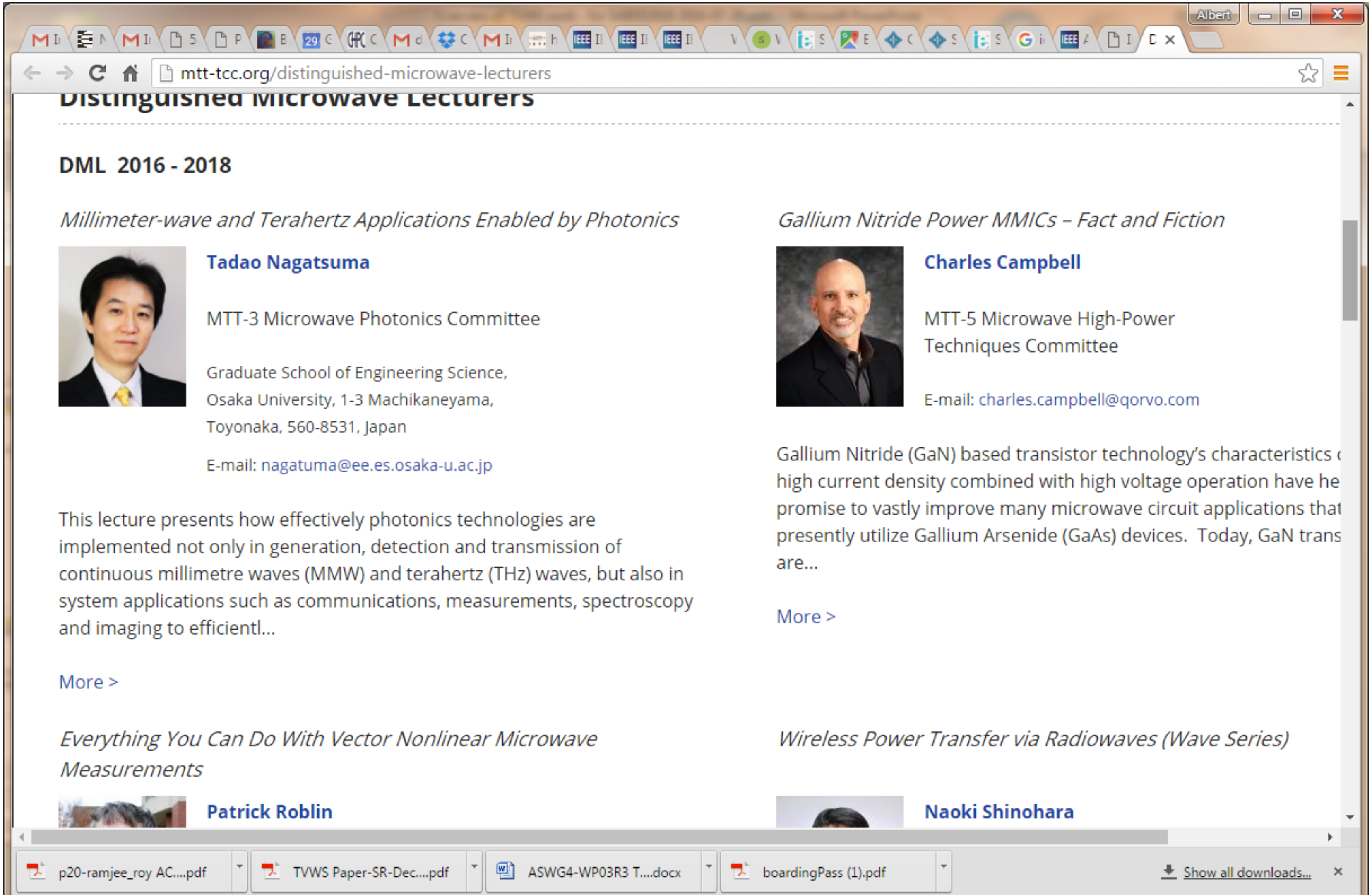
IEEE MTT DL

http://www.ieeeaps.org/education/distinguished-lecturer-program



IEEE EMC DL

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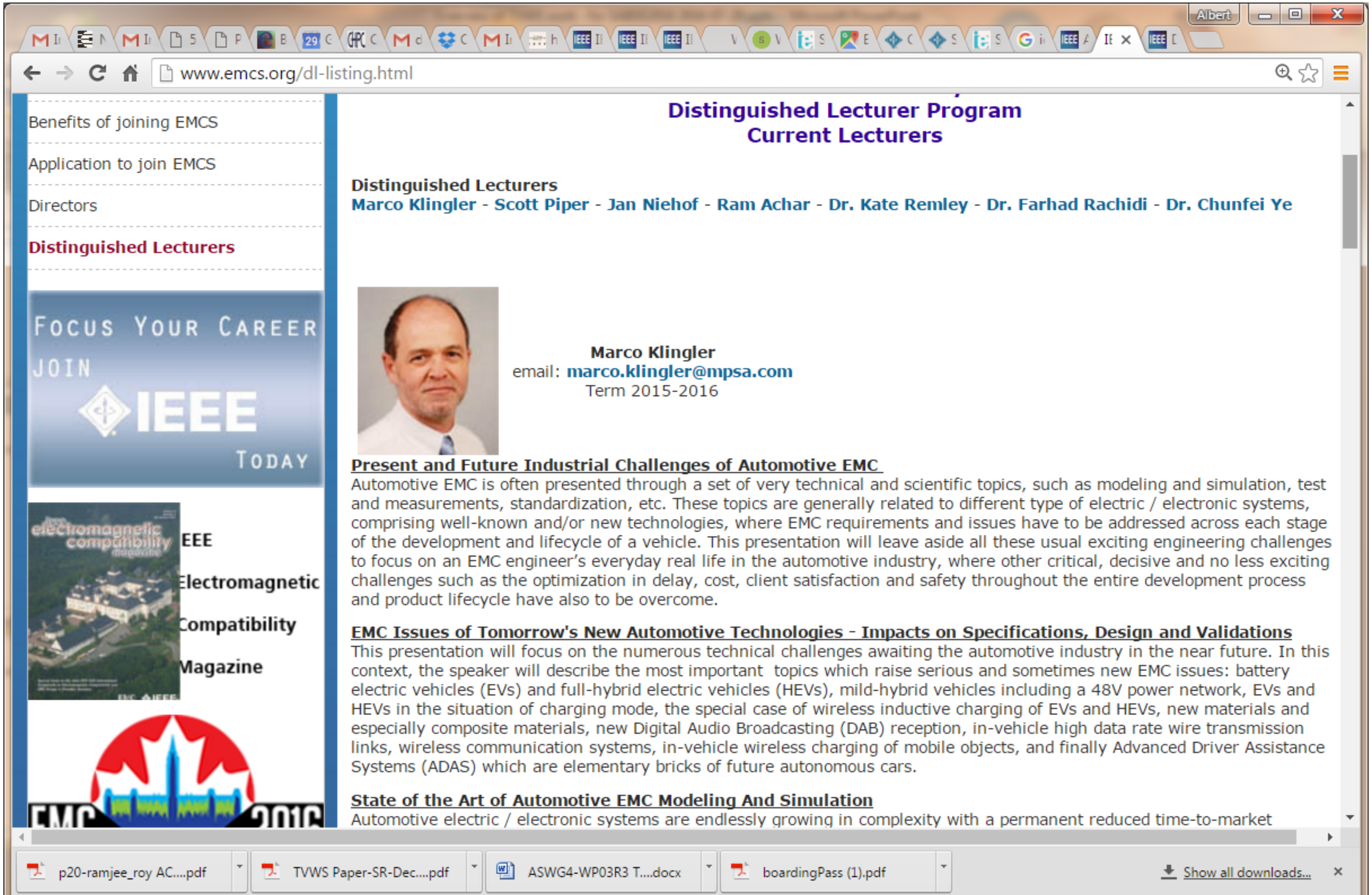

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Marco Klingler
email: marco.klingler@mpsa.com
Term 2015-2016

Present and Future Industrial Challenges of Automotive EMC

Automotive EMC is often presented through a set of very technical and scientific topics, such as modeling and simulation, test and measurements, standardization, etc. These topics are generally related to different type of electric / electronic systems, comprising well-known and/or new technologies, where EMC requirements and issues have to be addressed across each stage of the development and lifecycle of a vehicle. This presentation will leave aside all these usual exciting engineering challenges to focus on an EMC engineer's everyday real life in the automotive industry, where other critical, decisive and no less exciting challenges such as the optimization in delay, cost, client satisfaction and safety throughout the entire development process and product lifecycle have also to be overcome.

EMC Issues of Tomorrow's New Automotive Technologies - Impacts on Specifications, Design and Validations

This presentation will focus on the numerous technical challenges awaiting the automotive industry in the near future. In this context, the speaker will describe the most important topics which raise serious and sometimes new EMC issues: battery electric vehicles (EVs) and full-hybrid electric vehicles (HEVs), mild-hybrid vehicles including a 48V power network, EVs and HEVs in the situation of charging mode, the special case of wireless inductive charging of EVs and HEVs, new materials and especially composite materials, new Digital Audio Broadcasting (DAB) reception, in-vehicle high data rate wire transmission links, wireless communication systems, in-vehicle wireless charging of mobile objects, and finally Advanced Driver Assistance Systems (ADAS) which are elementary bricks of future autonomous cars.

State of the Art of Automotive EMC Modeling And Simulation

Automotive electric / electronic systems are endlessly growing in complexity with a permanent reduced time-to-market

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IEEE Distinguished Lecturership programme (2)

- Can invite Distinguished speakers
- Can become a Distinguished Lecturer

- Sponsored by respective IEEE Societies
  - USD1000-2500
- How to

http://ieee.org.za/inviting-ieee-distinguished-lecturer-dl-south-africa

ADDITIONAL SLIDES

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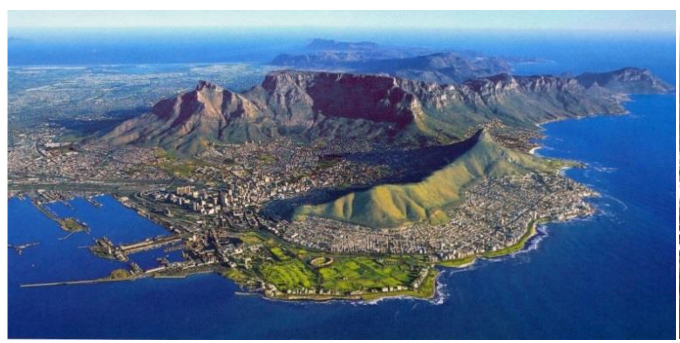
South Africa - known

- Prime tourist destination
  - Widest flora in the world
  - Hosted FIFA World Cup
- 1.2M km2
- GDP(PPP) US725B

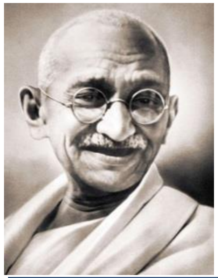
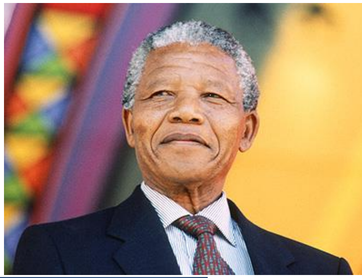


https://en.wikipedia.org/wiki/South_Africa

South Africa – less known

- South Africa, 53M people:
  - Had 6 nuclear war heads and developed ballistic missiles and in 90s… self-dismantled the programs (the first and, likely, the only country in the world)
  - Social transformations with no revolutions
    - “Birth” of Ghandi and Mandela
  - First radar built and demonstrated by 1938
  - Birthplace of Mark Shuttleworth, Elon Musk etc.
  - **Many companies in electromagnetics, radar & such**
    - including specializing in antennas like Poynting, EMSS / FEKO and strong radar industry (SAAB Grintek, Tellumat, RRS, EDH, CSIR DPSS, ...)
    - all actively exporting their production
  - **Won half of the multi-billion Euro bid for SKA (Square Kilometer Array)**
  - Eligible to participate in EU FP8, Horizon2020 etc; one of the most successful participants from Africa




http://en.wikipedia.org/wiki/South_Africa_and_weapons_of_mass_destruction
https://en.wikipedia.org/wiki/List_of_South_Africans

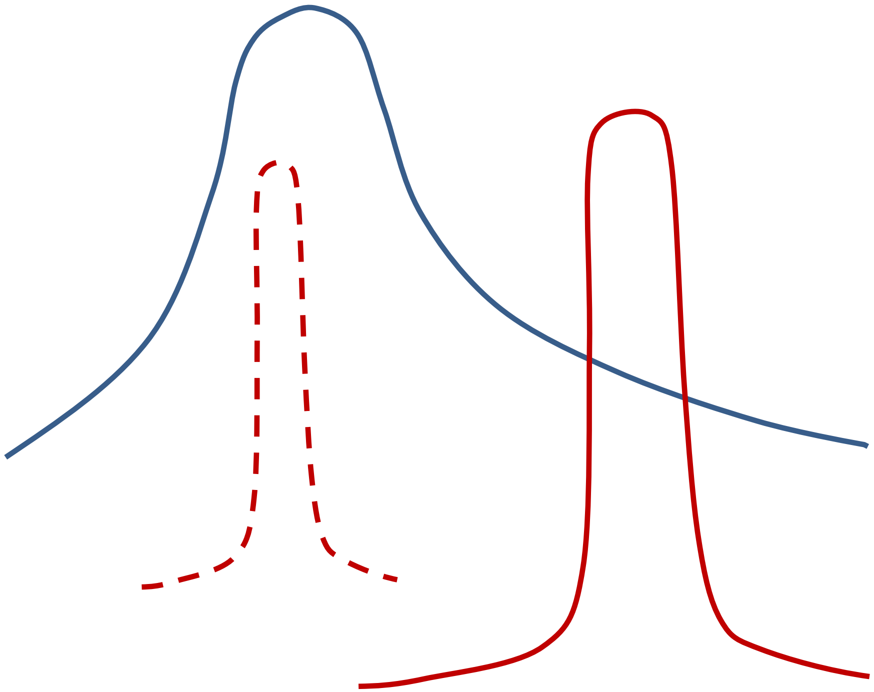
NICT in London: UDP 45.5Mbps in 40MHz using LTE

- The maximum transmission power is 1 W for a base station (eNB), and 100 mW for a user terminal (UE)[3].
- an LTE base station situated on the roof of a building in the Denmark Hill campus of King's College London, and transmission speed measurements were made while moving an LTE terminal around within the campus. From the results of these measurements, we found that the maximum UDP downlink transmission speed was 45.4 Mbps during FDD operation with two sets of 20 MHz bandwidth, and 19.5 Mbps during TDD operation with a 20 MHz bandwidth

- [Kentaro Ishizu, *An Overview of the Ofcom (UK) White Spaces Pilot*, and the Involvement of the NICT, New Breeze Summer 2015, pp. 24-25]

Why all this fuss about regulating spectrum?

- **Interference**
  - Co-channel
  - Adjacent (and beyond) channel
  - Desentization
- Defined by both: power and spectrum shape of interferer and sensitivity curve of receiver



Key trials in South Africa

- **South Africa**, Limpopo - Microsoft trial to 5 underserviced schools Q1 2014: purpose– demonstrate WS in underserved communities; Cape Town trial has demonstrated possibility of usage of adjacent channels (likely, first in the world on a large scale);
  - FCC is now referring to our trial and considers to soften the regulations in USA
- **Ghana** – 2 trials (incl. one with CSIR support)
- **Kenya**, rural Laikipia County – 108 km^2 : Microsoft trial 3 schools, 2 healthcare clinics, 2 businesses
- **Tanzania**, Dar es Salaam – Microsoft trial for 2014 starting with 4 universities in Dar es Salaam
- **Malawi**, Zomba - TVWS trial with support of Wireless Marconi lab at ICTP schools, hospital (20km), Seismology department, Malawi Defence Force airwing – 1st Omni WS trial with Carlson Wireless equipment
- **Namibia** – Largest TV White Space trial in the world – 28 schools covering 62km x 152 km = 9424 km^2 - Microsoft/Adaptrum
- **Several trials across the globe (USA, Singapore, UK, incl. another very large trial which started in UK, etc.)**

Our TVWS/CR-related research groups

- Two research groups:
  - **Pretoria**: Trials, GLSD
  - **Cape Town**: TVWS devices
- 15+ people incl. 4 PhDs (2 more in progress)
- Focus on wireless research, especially targeting rural and under-served areas
- Close links with the Department of Telecommunications and Postal Services (DTPS), local spectrum regulator ICASA (MoU), and SENTECH and other government structures
- Collaborations with local (UCT, TUT, UP, UL, …) and foreign universities and industry (Parsec/Redline Telecom SA, Telumat, …, Google, Microsoft, …)

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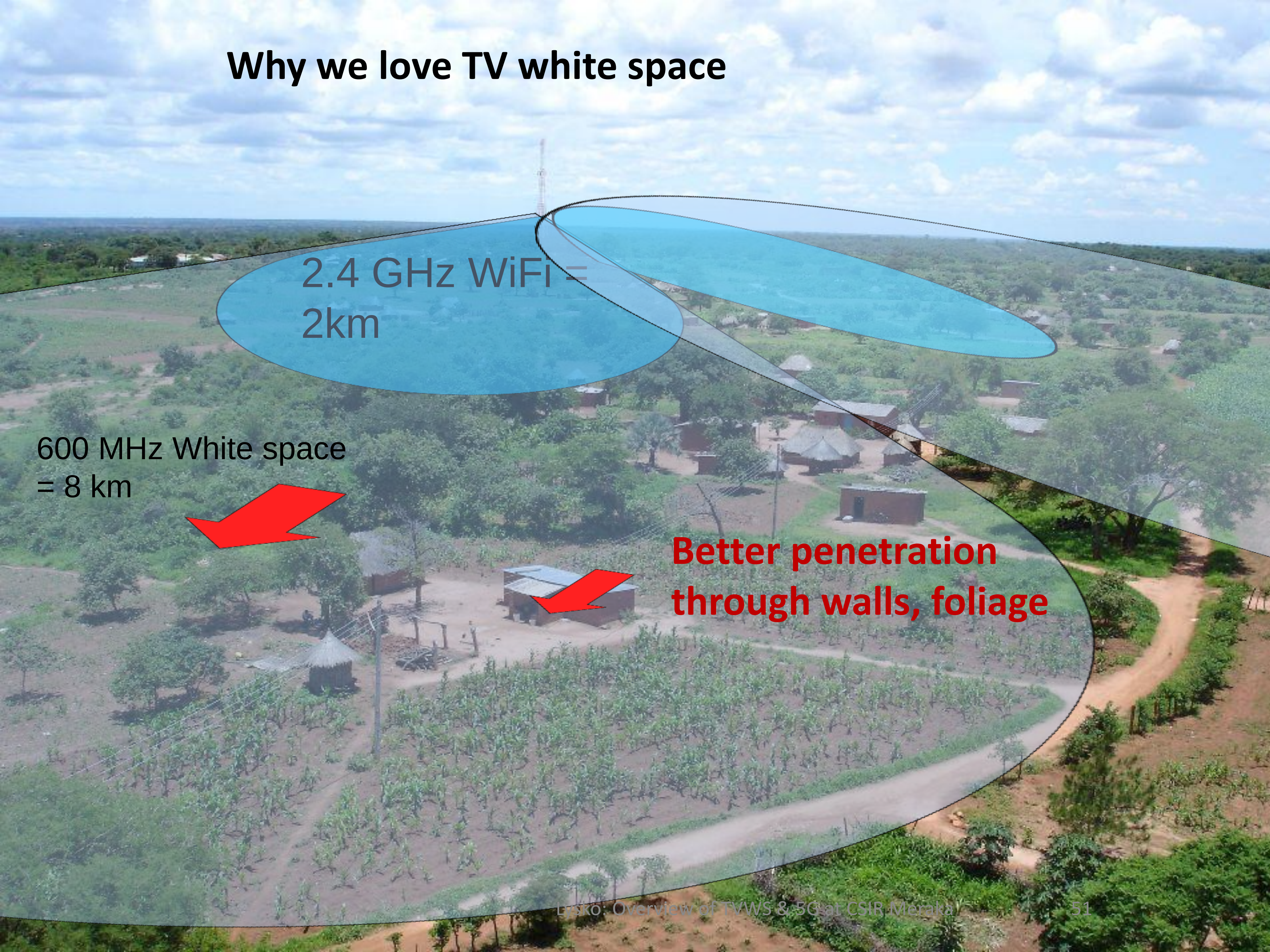
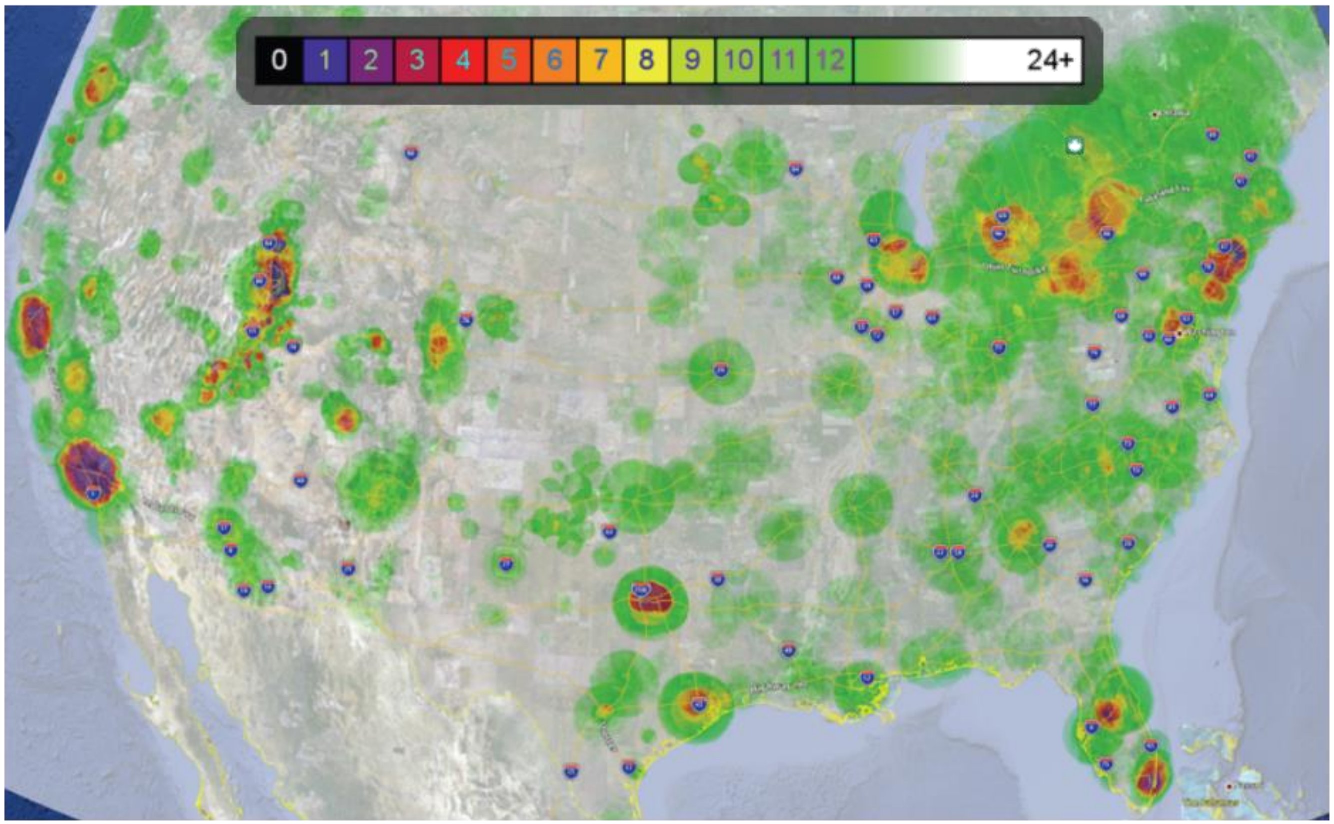


Why we love TV white space
2.4 GHz WiFi = 2km
600 MHz White space = 8 km
Better penetration through walls, foliage

White space availability US

TV White Space Channel Availability

Page 6



Google Confidential and Proprietary

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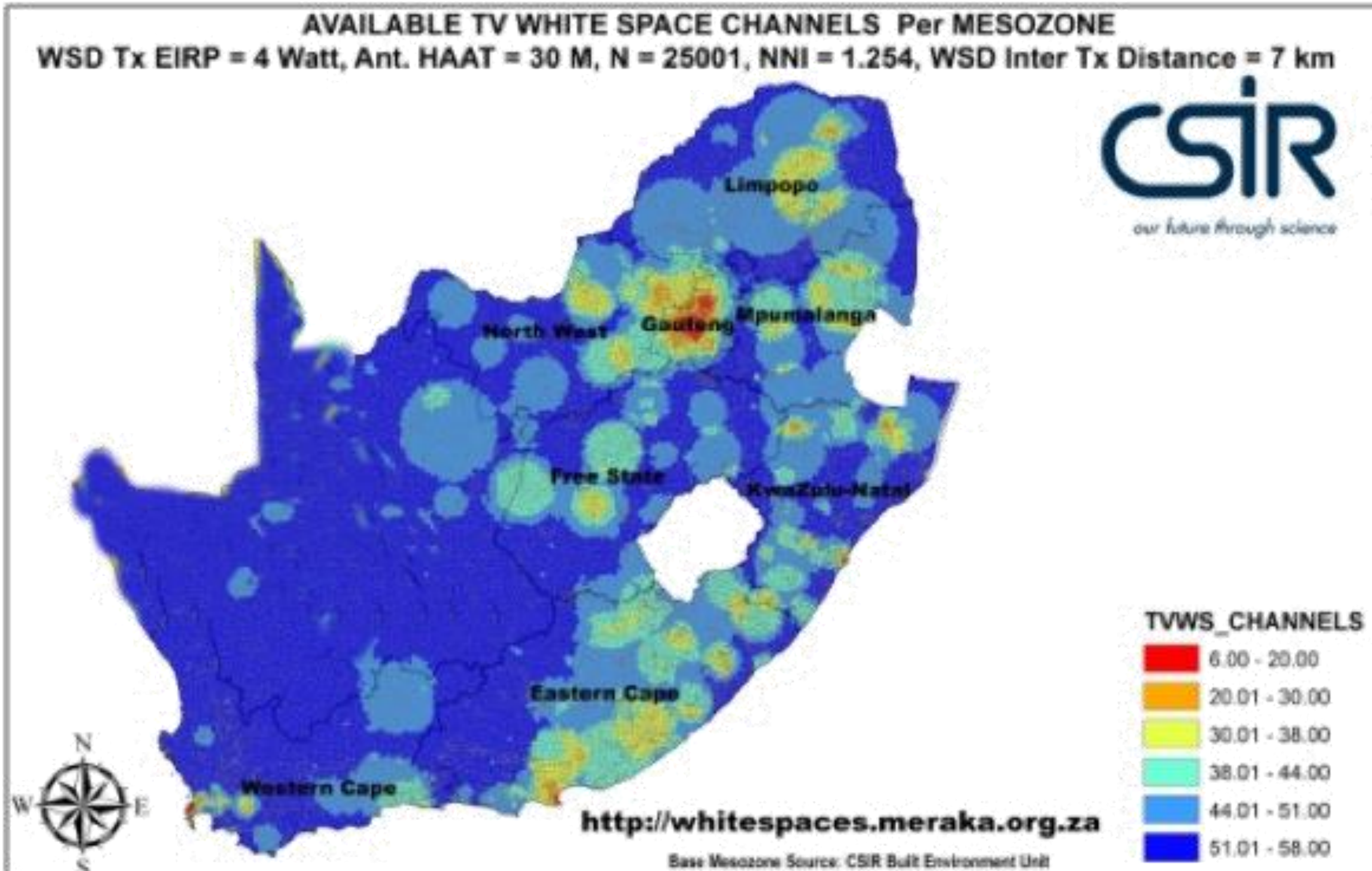
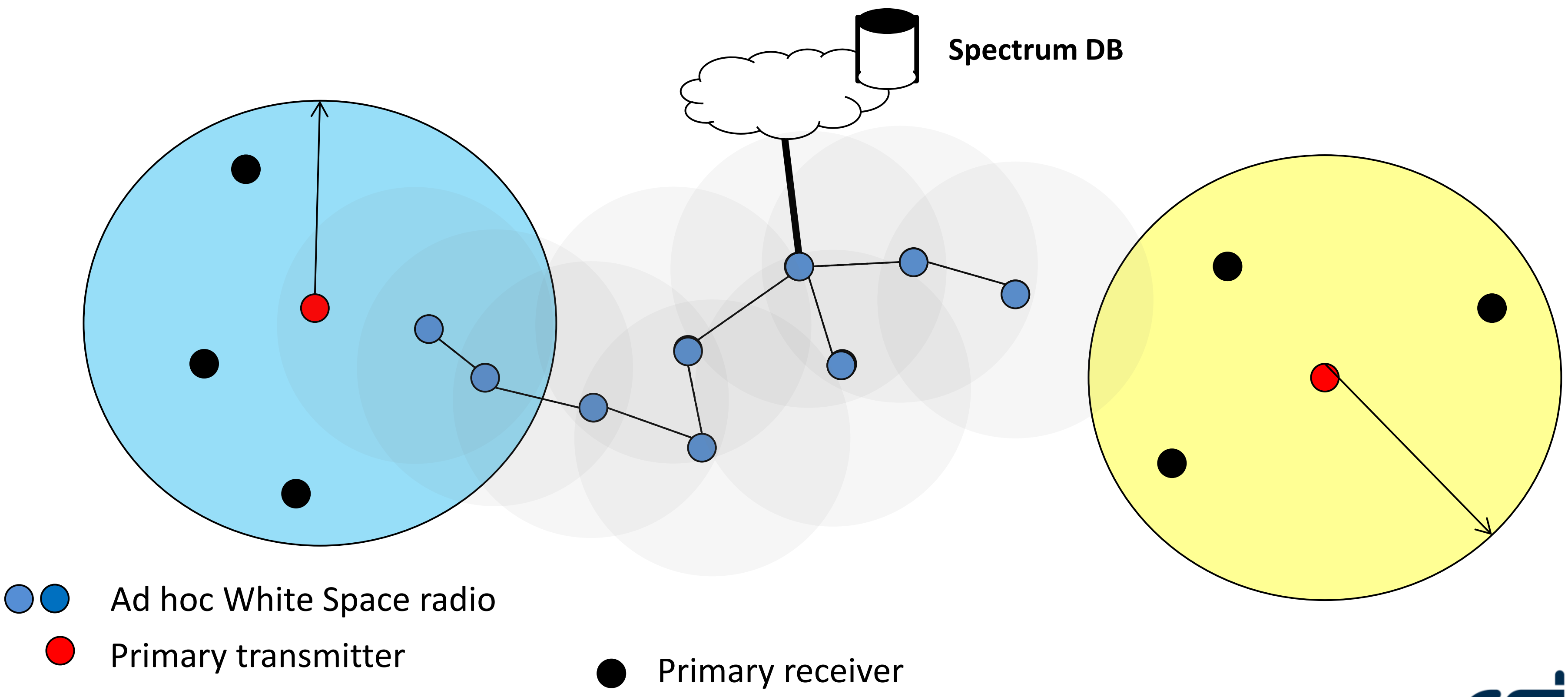
White space availability SA (pre - digital dividend)



What's next

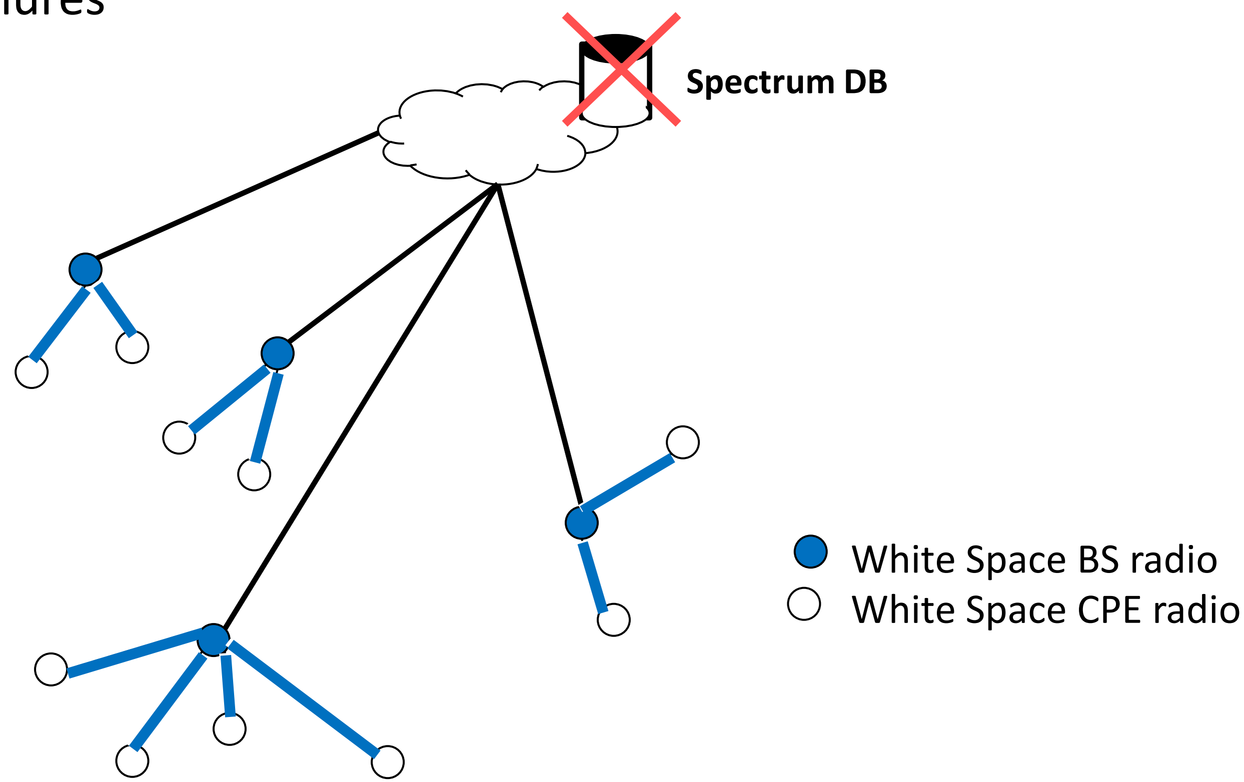
White space ad-hoc/mesh networks channel allocation



Keeping white space networks alive

- No contact with Spectrum DB -> all WS connected to DB shut down
  - Political interference (Egypt, Syria)
  - Natural disaster
  - Network failures

→ Move to reserved survival channel (Low bandwidth)



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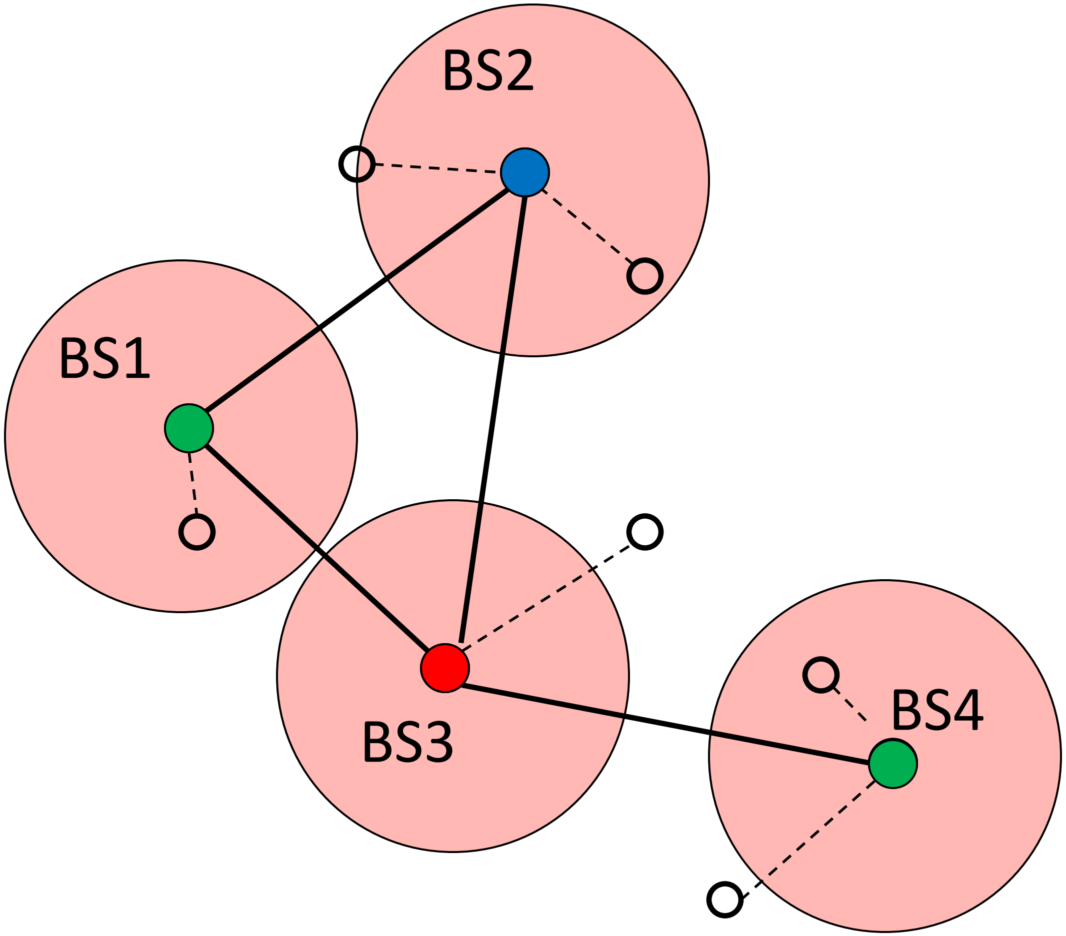
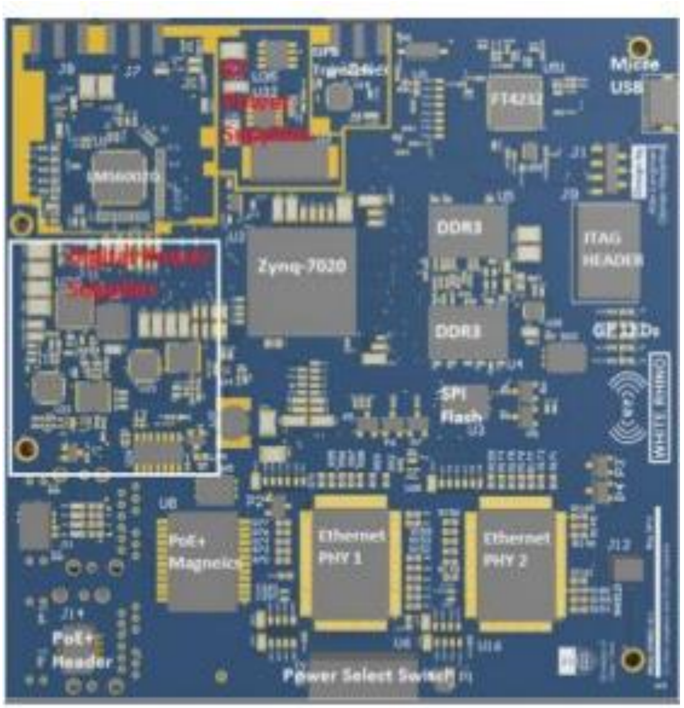
Smarter Channel allocation for secondary users

Channel search space selected from distribution weighted towards

1. minimizing interference from other cells and
2. maximizing signal quality to clients

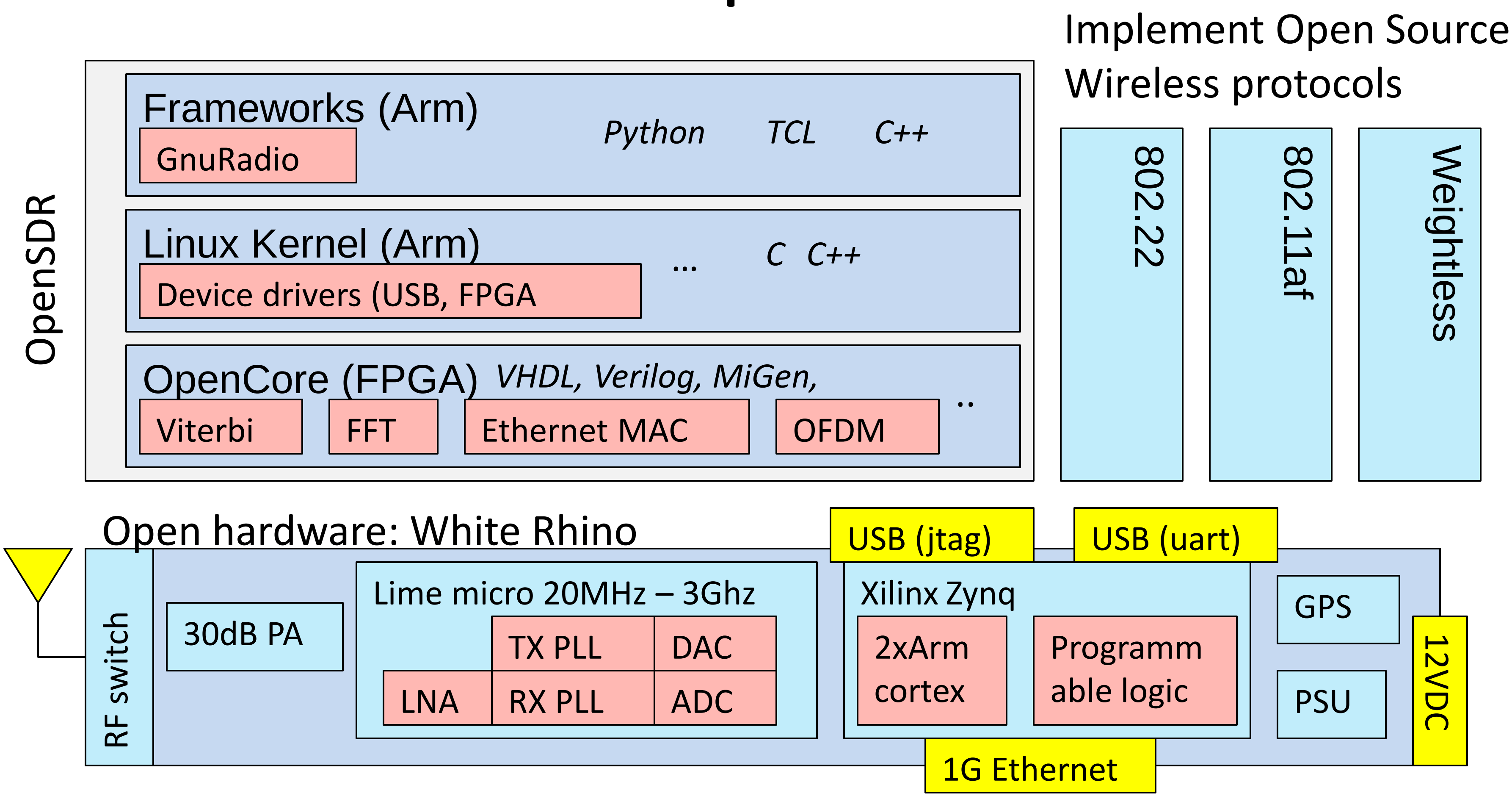


SDR - White Rhino board - UCT



- Developed at UCT in Radar group
- Evolved from Rhino – low cost FPGA-based board for astronomy applications
- Xilinx Zynq 7020 + dual core 1GHz ARM
- RF transceiver 300 MHz to 3 Ghz
- 36 dBm Final stage amp
- Built-in GPS

Need an the “OpenBTS” of TV white space



How will 2016 look

- SA Government has published white space white paper with call for comments due 29 Jan 2016
- Draft regulations possible by April 2016
- Finalized regulations sometime in 2016?
- CSIR trial of White Space mesh across 6 sites in Cape Town covering 30km by 20 km area – extending Google trial
- Lots more collaborative spectrum sensing work
- Continue development of White Rhino
- OFCOM certification of CSIR geo-location spectrum database

South Africa White Space trial Cape Town

- Sponsored by Google
- Purpose: demonstrate broadband over WS with no interference to TV
- Goal: Set broadcasters at ease. Help formulate policy for SA.
- US equipment - Carlson Wireless (500mW) with 9dBi antennas (approx 4W EIRP)
- 3 sectors connecting 10 schools from Tygerberg hospital

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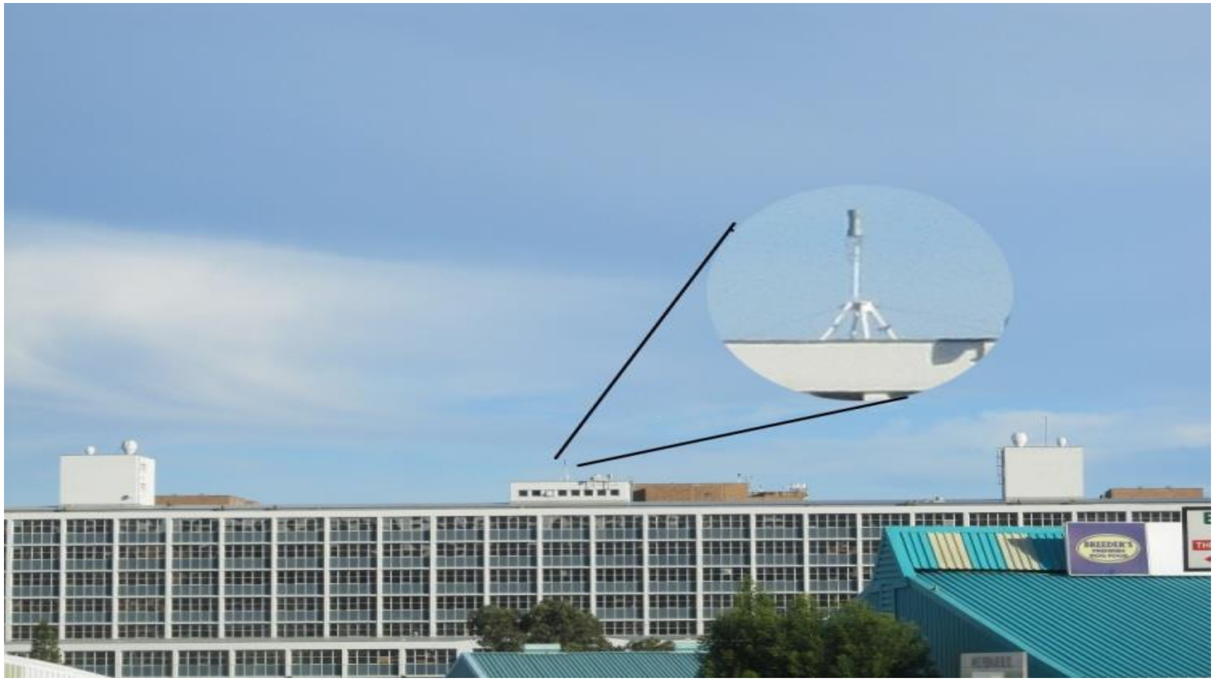
South Africa White Space trial Cape Town



e-Schools' Network

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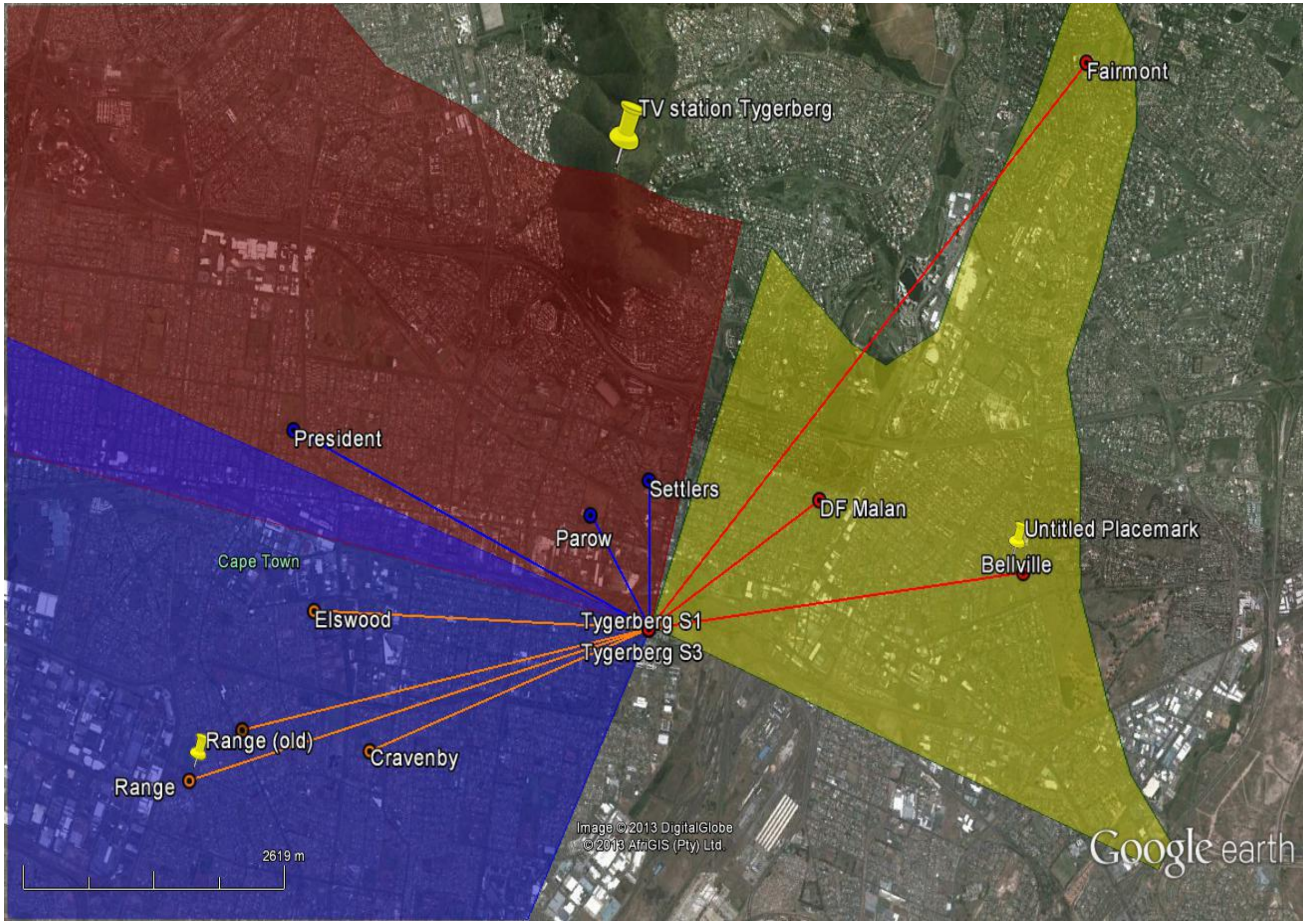
Google

comsol WIRELESS SOLUTIONS

TENET Tertiary Education and Research Network of South Africa

WAPA WIRELESS ACCESS

TVWS trial in Cape Town - network



3 sectors connecting 10 schools

Longest link 6.5km

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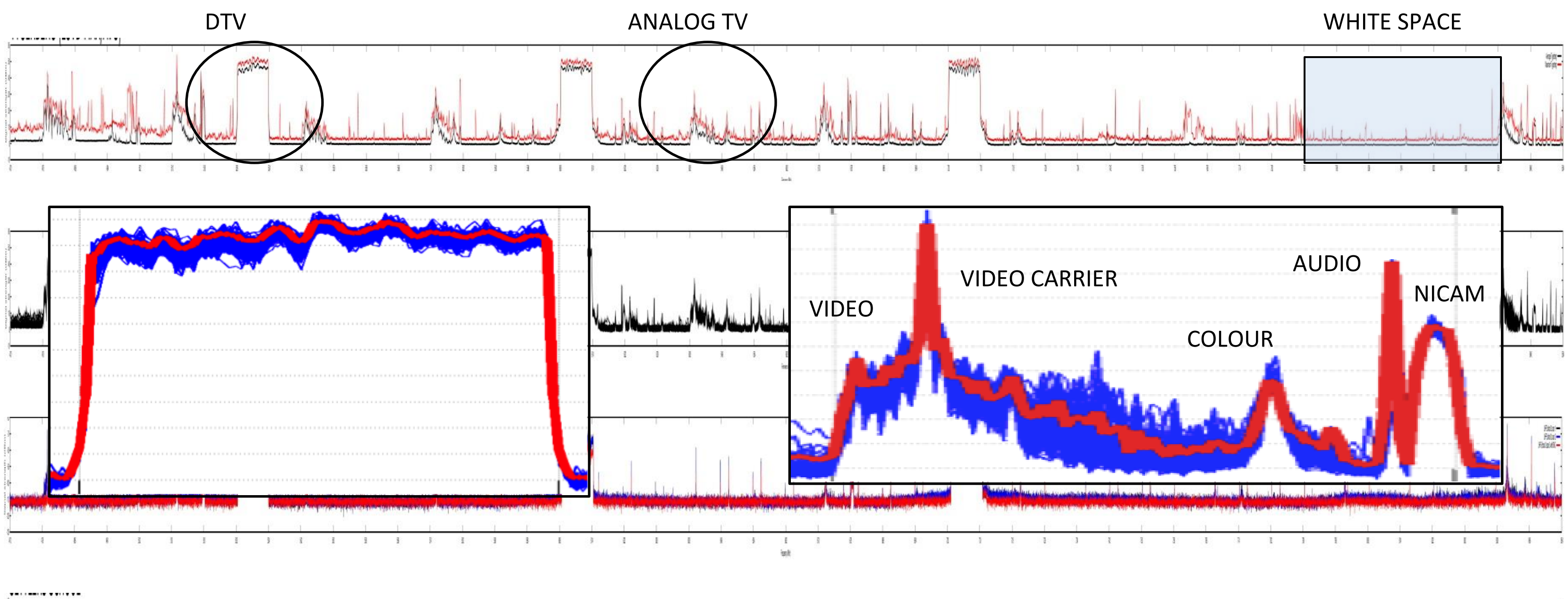
Cape Town Trial: background

- Cape Town chosen due to large amount of TV transmitters (analog+digital) in area – worst



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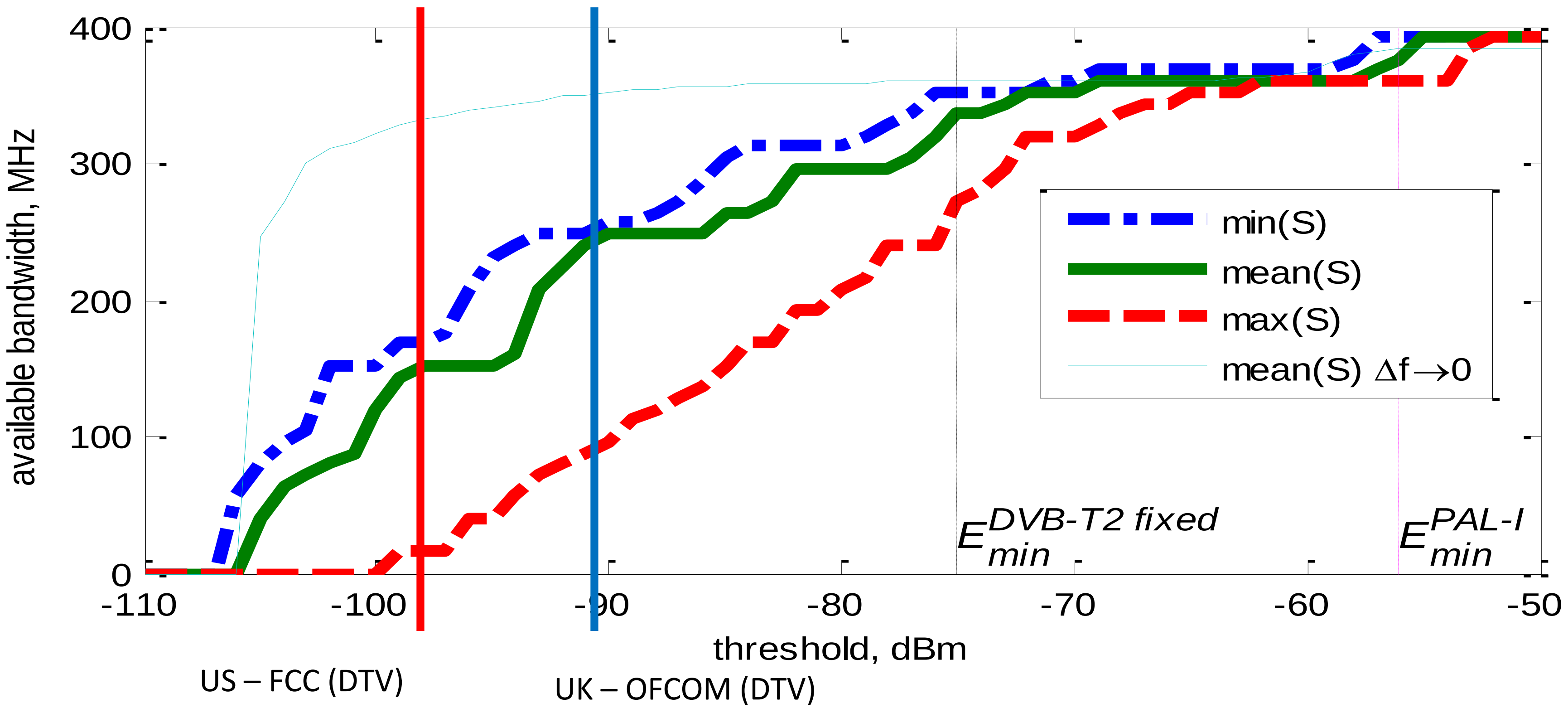
Availability of TV White spaces in Cape Town



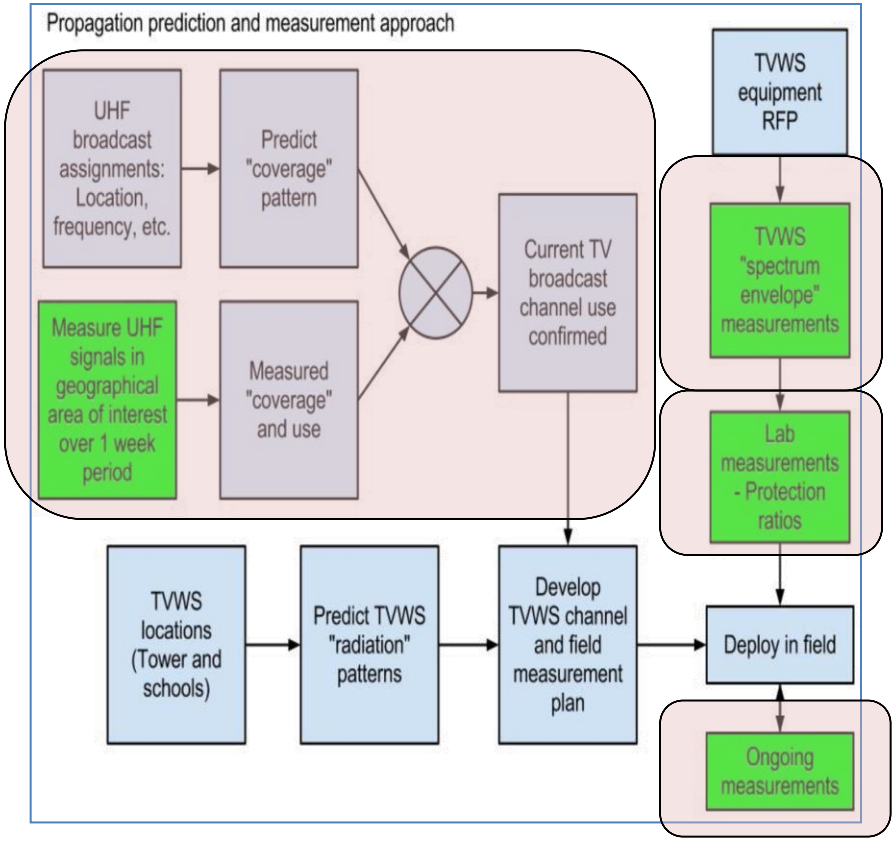
- **Selected six candidate channels to use for TVWS trial**

[A. Lysko, M. Masonta, and D. Johnson, Chapter "Television White Space Opportunity in South Africa: From Field Measurements to Quantifying the White Space" in book "White Space Communication: Advances, Developments and Engineering Challenges, Springer, 2014]*

TRIAL Objective and sequence of actions

•Ensuring non-interference

- Identify availability of white space in terms of unused and underused frequency bands
    - at the desired location, for the desired period of time, by analysis based on existing data and measurements;
- Test white space equipment to ensure
    - Correct spectrum power mask/envelope;
    - Correct behaviour;
- Estimation of the protection ratios and actual availability of white space in terms of the WSD's and TV performance parameters;
- Monitor for interference during operation.



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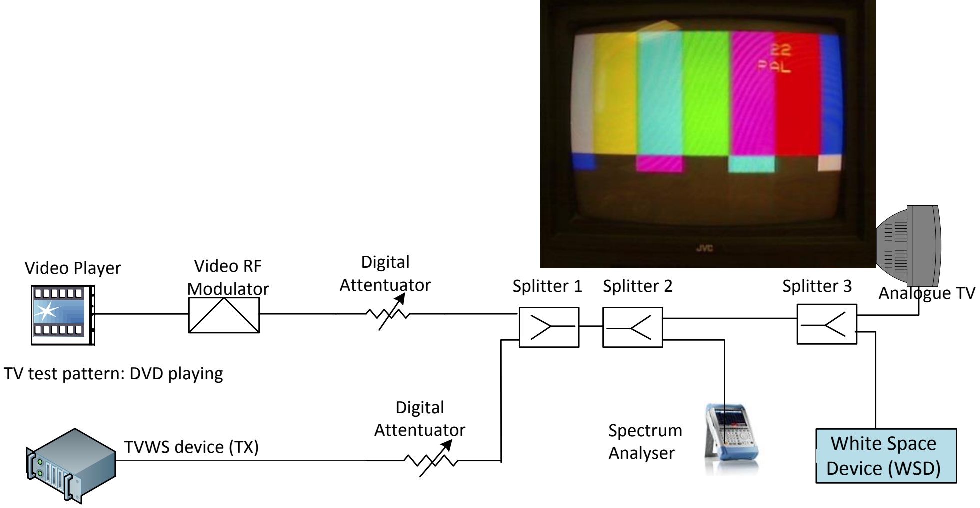
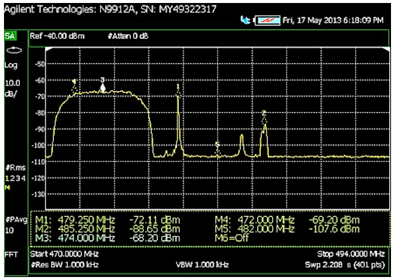
Trials



<u>Typical set of tests we perform</u>:

- Laboratory testing
  - Power, Spectrum mask, Bandwidth
  - EMC/EMI
  - Dynamic behaviour (boot up, channel switch, control, …)
  - Protection ratio determination (PAL-I, DVB-T2)
  - Network performance (throughput, latency)
  - etc.: Device dependent (P2P vs P2MP, interference, MIMO channel dis-balance, …)



- Radio planning of TVWS network
- Pre-trial spectrum scans
- Spectrum and network performance measurements during trial

http://www.tenet.ac.za/tvws

http://www.tenet.ac.za/tvws/cape-town-tv-white-spaces-trial-field-measurements-report-1

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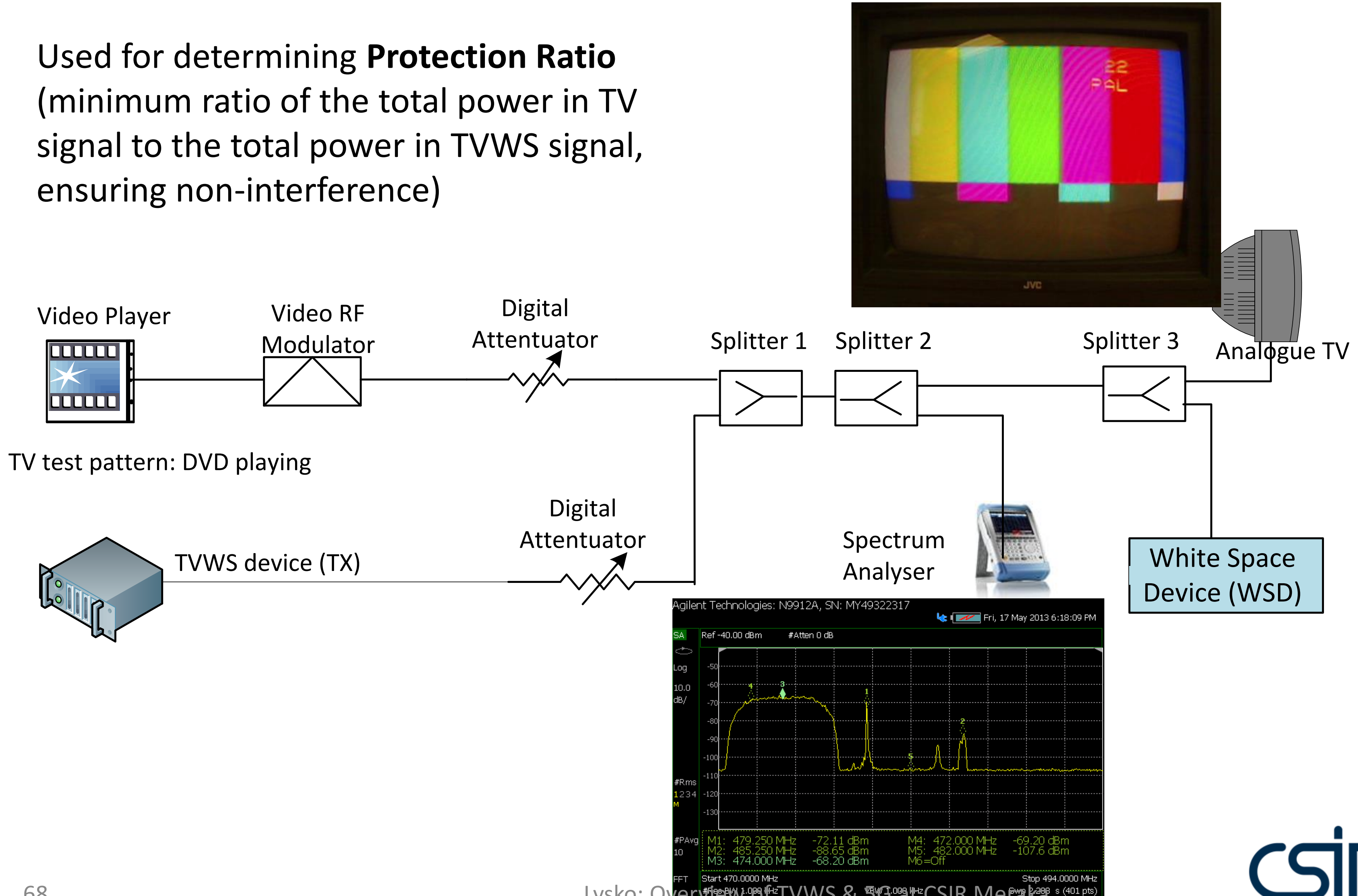
Lab measurements to measure interference to TV

Used for determining **Protection Ratio** (minimum ratio of the total power in TV signal to the total power in TVWS signal, ensuring non-interference)



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Results Cape Town Trial

- No Interference reported
- Used some white space channels adjacent to TV channels (even between 2 TV channels)
  - Led to FCC 14-144 - reconsider rules of not allowing adjacent channels provided there is sufficient distance from contour or lower power level (Sep 2014)
- Theoretical calculations show use of adjacent channels would only pose problem if WSD < 200m from TV
- Achieved 12 Mbps (TCP) up to 6.5 km away (QAM16).
  - Current state-of-the-technology is QAM 64 produces a throughput of 22-26 Mbps over an 8 MHz channel

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TVWS trial in Limpopo Province

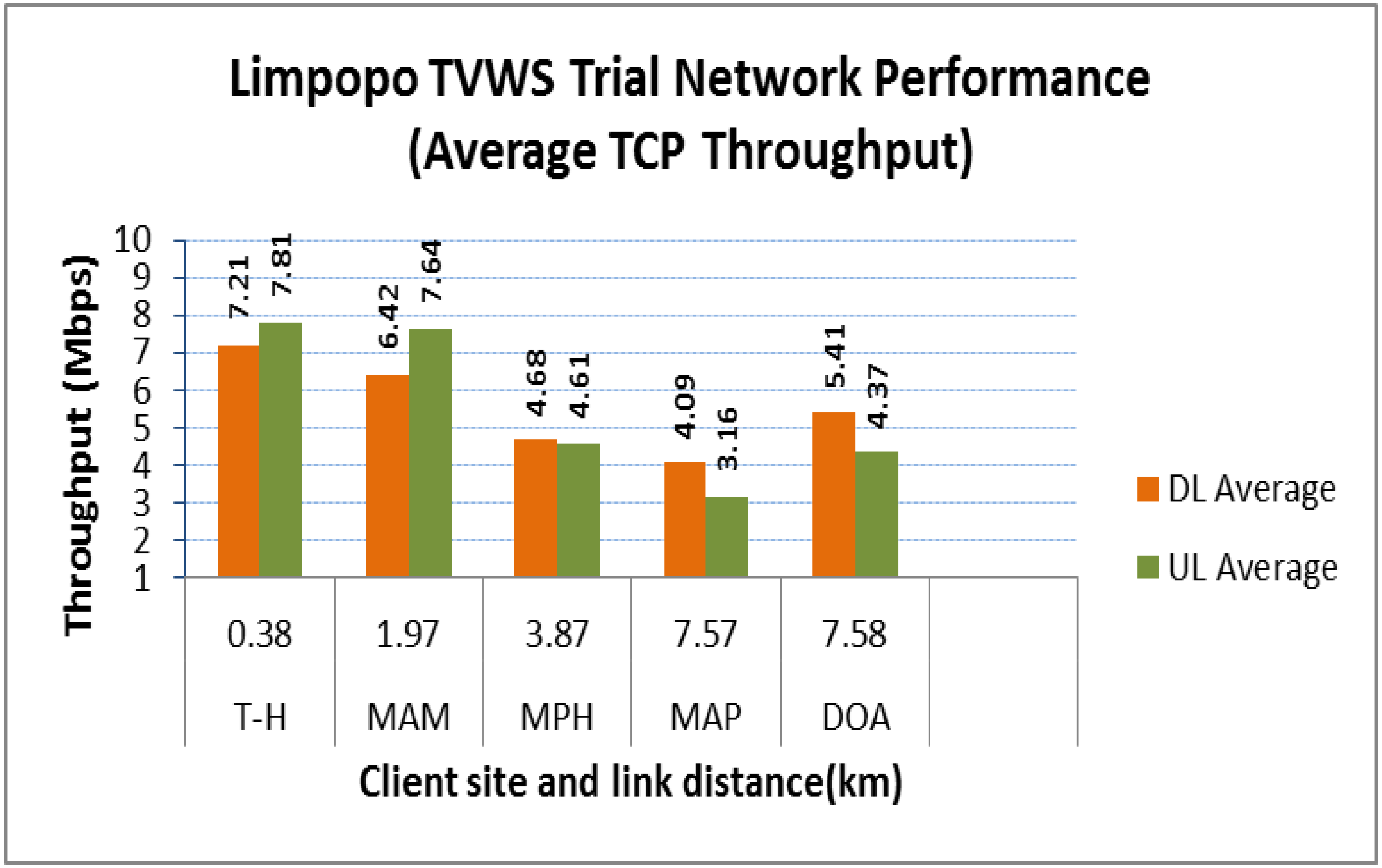
- Sponsored by Microsoft – 4Africa programme
  - Provided Tablets and organized training
- Connected 5+1 schools (incl. a 2-hop link)
- Hardware from 6Harmonics (WiFi-like cards)
- Geolocation spectrum databased by CSIR

Limpopo trial – location of nodes

Max link length ~ 8 km

[Masonta, Kola, Lysko, Pieterse, Velempini, Network Performance Analysis of the Limpopo TV White Space (TVWS) Trial Network, SATNAC 2015]

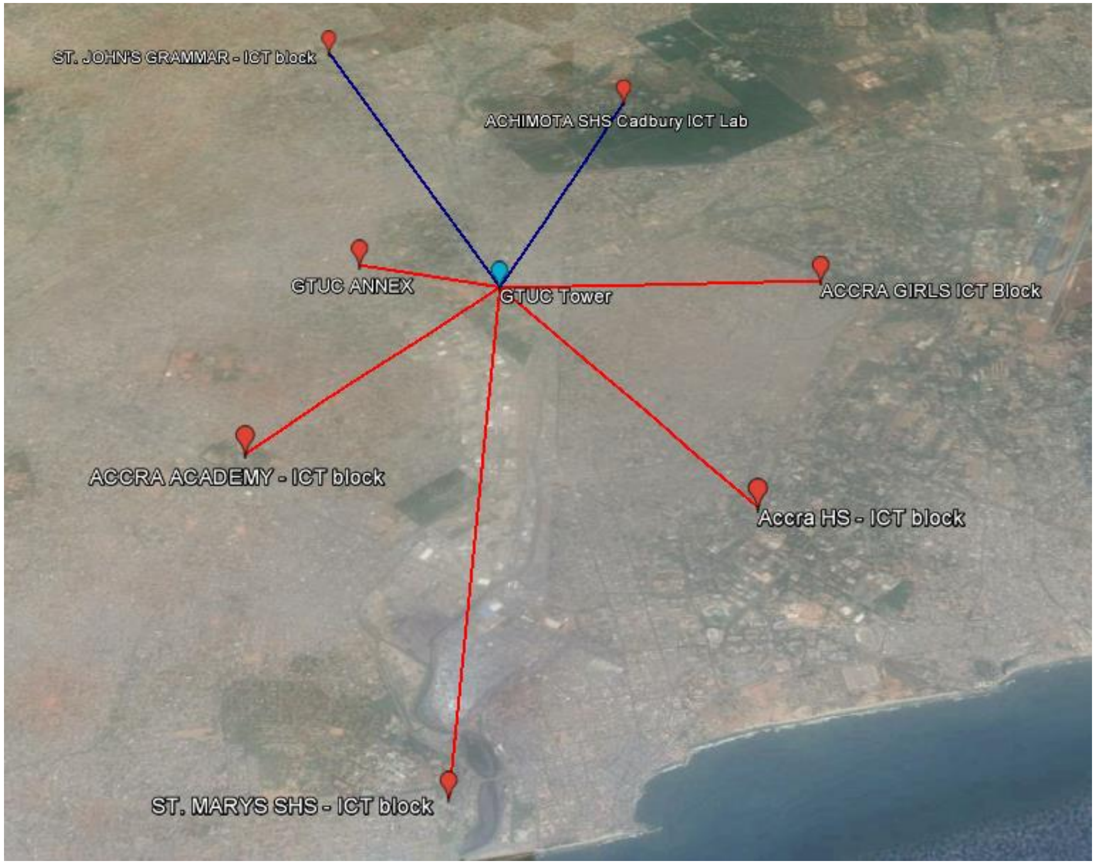
Network performance in Limpopo



[Masonta, Kola, Lysko, Pieterse, Velempini, Network Performance Analysis of the Limpopo TV White Space (TVWS) Trial Network, SATNAC 2015]

Ghana trial

- 7 user sites
- 9714 users:
  - 9163 students
  - 551 teachers
- User both Carlson Wireless (links show in red) **and** 6Harmonics (links shown in blue)



ICASA call for comments on TVWS

ARTICLE | COMMENTS | OTHER NEWS | RESEARCH | MAGAZINE

OCT 23, 2015

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Icasa calls for comment on white space spectrum

Now extended to Jan 29, 2016

BY: NATASHA ODENDAAL
CREAMER MEDIA SENIOR CONTRIBUTING EDITOR ONLINE

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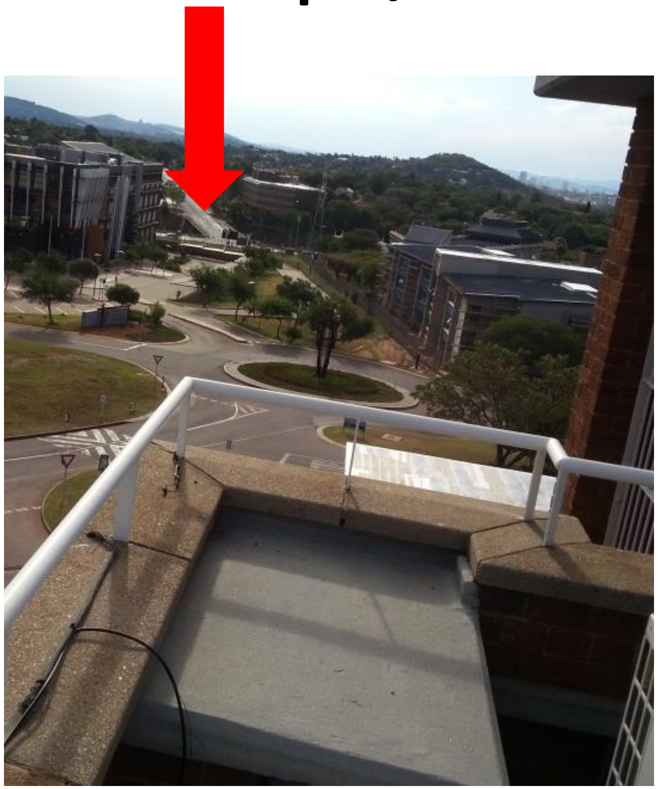
The Independent Communications Authority of South Africa (Icasa) is calling on industry to comment on proposed regulations concerning the underused television white space (TVWS) spectrum.

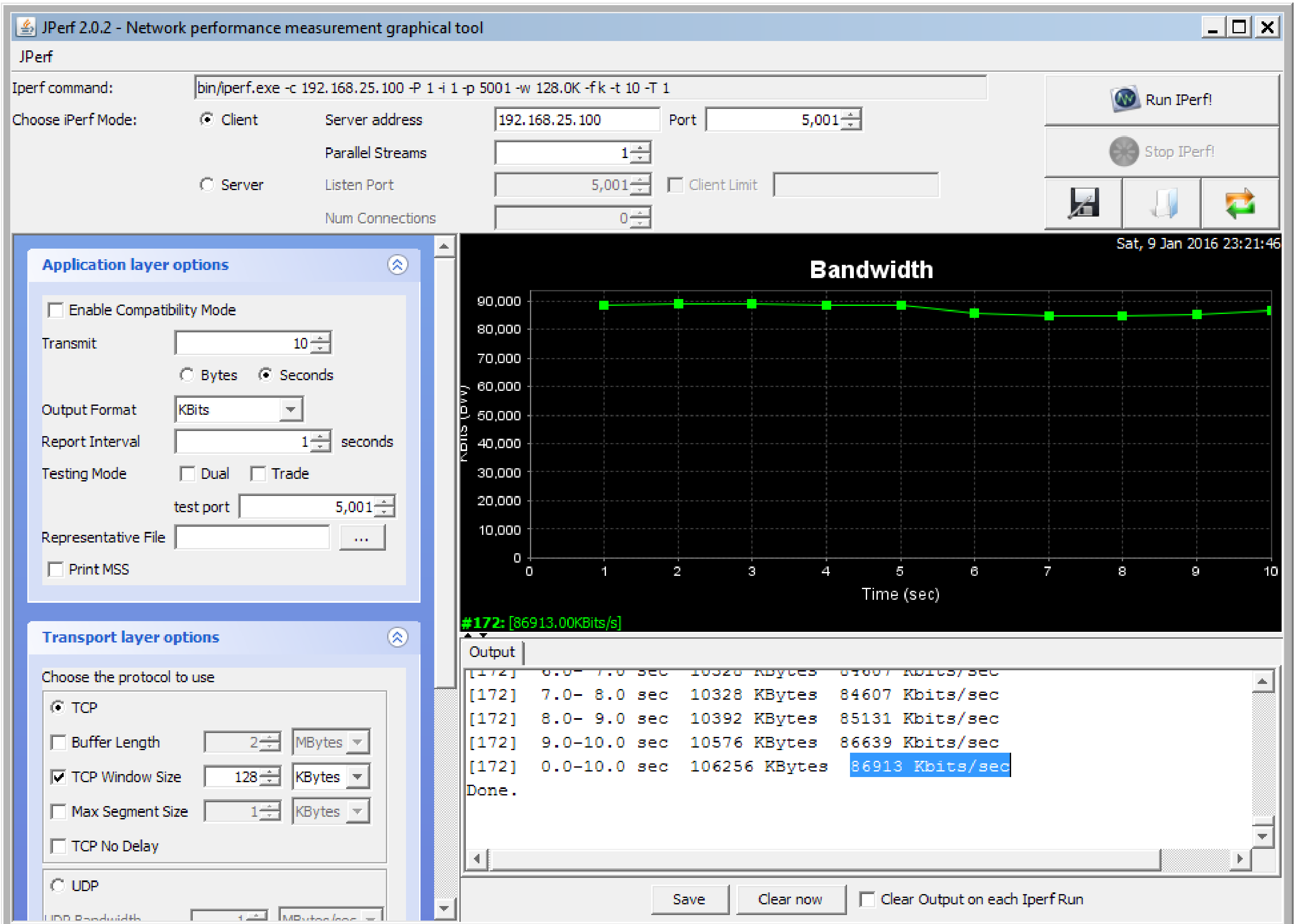
Stakeholders had until December 18 to provide input into the draft discussion document on Dynamic and Opportunistic Spectrum Management, which proposed opening up the 470 MHz to 694 MHz band, currently used for terrestrial broadcasting, for broadband services on a secondary user assignment basis.

"The proposed regulatory framework for dynamic spectrum assignment would enable the widespread use of this underused spectrum and, in doing so, promote more efficient use of available spectrum. This paper also addresses the issue of what form the licensing framework for TVWS should take," the regulator commented.

87Mbps/ 2.5ms on short 430m link (1)



87 Mbps, 2.5ms on short 430m link (2)



WSMN connection options