High Speed E-Band Wireless Communications Systems:
Technical Challenges and Applications

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WS9: E-Band Technologies and Applications

Outline

- Millimetre Wave Communications Overview
- Challenges for E-band Wireless Transmission
- CSIRO E-band Solutions
- Further Improvements
- Conclusions

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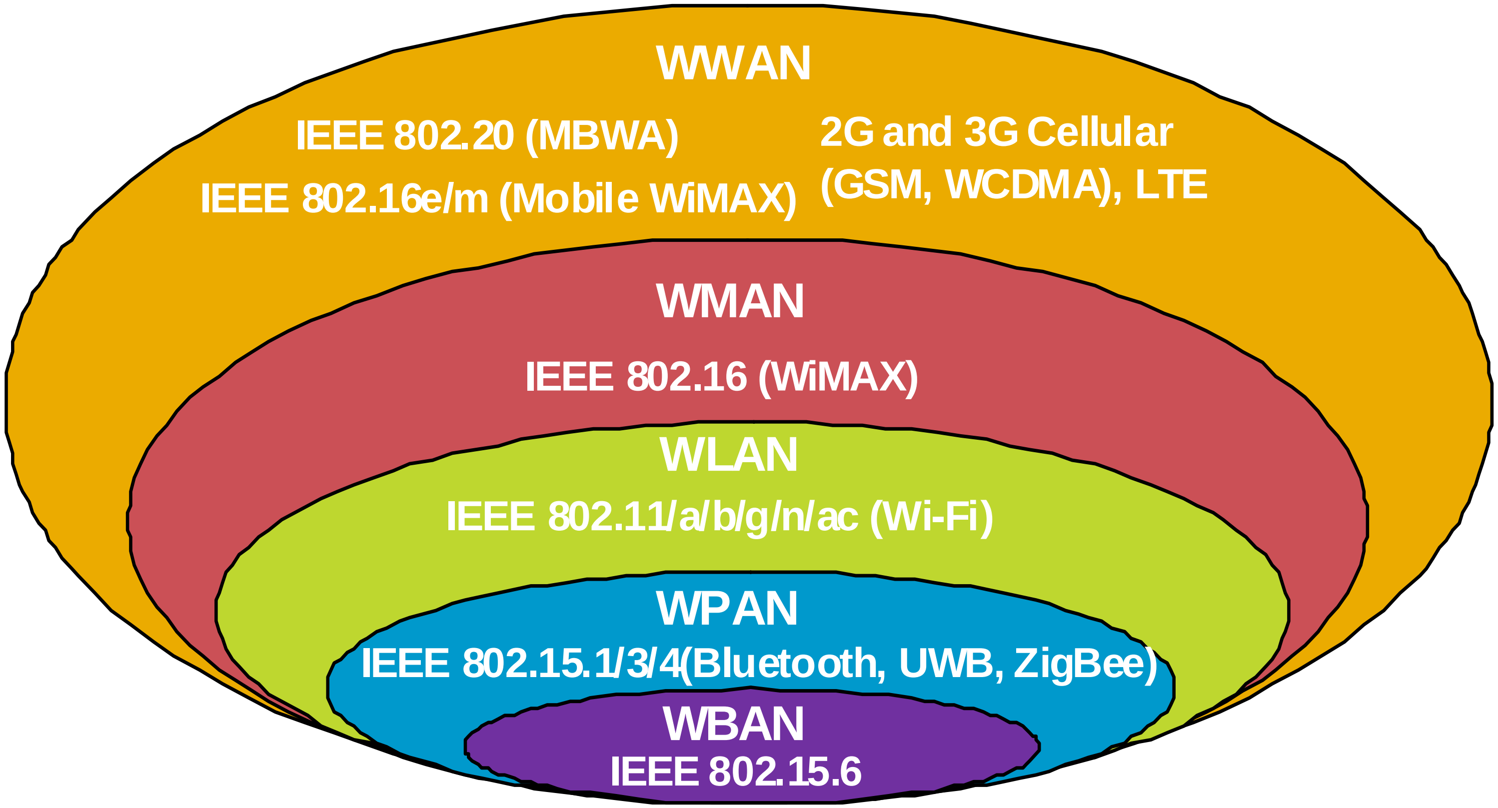
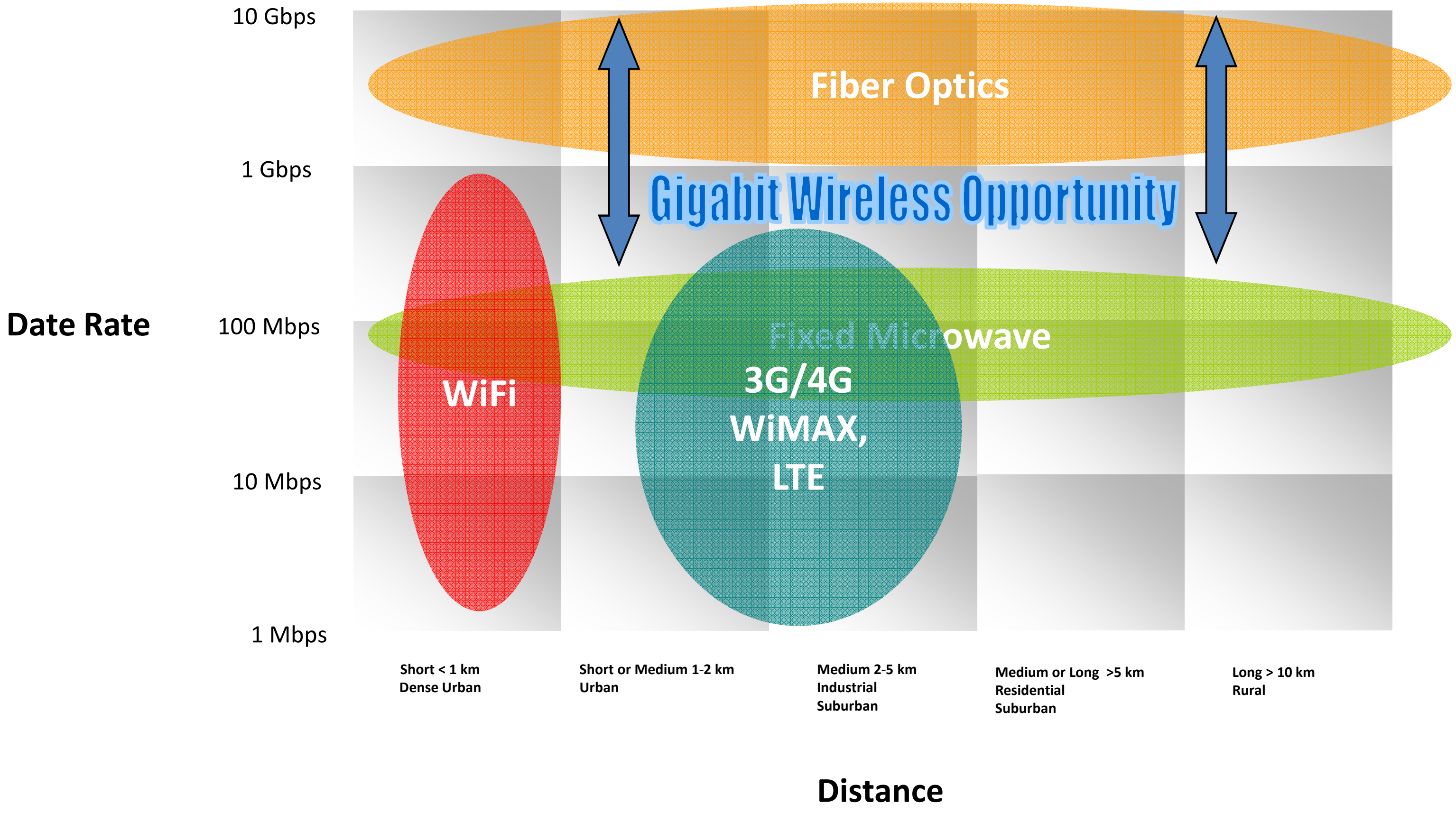
Wireless Landscape: Network Scale

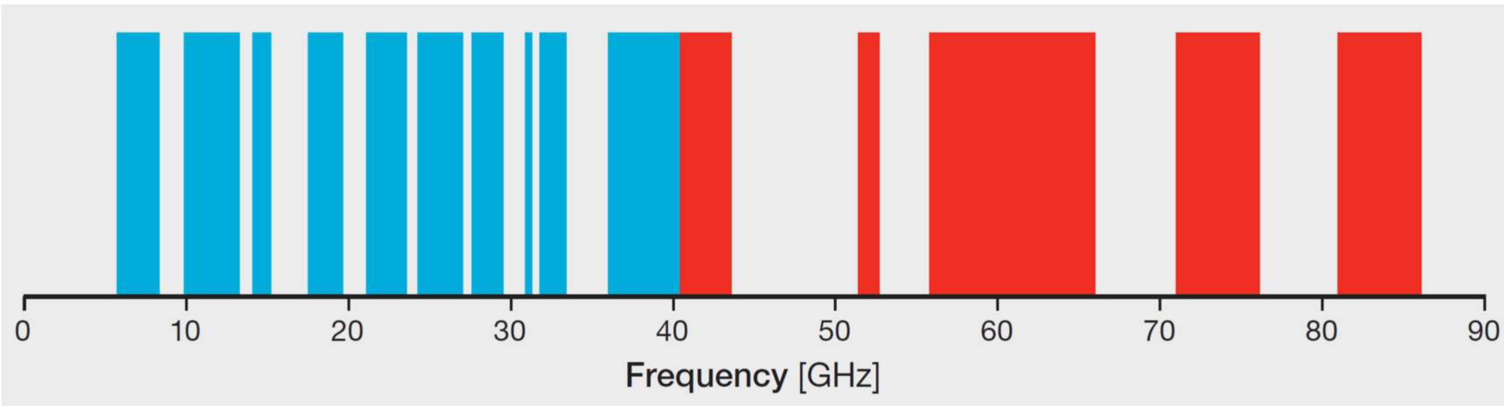


Wireless Landscape: Data Rate vs Mobility



Microwave and Millimetre Wave

- The widely used and globally available bands of 6-40 GHz (commonly called microwave bands) are relatively consistent in characteristics and are managed similarly
- The bands at 55 GHz and above have different atmospheric propagation characteristics and are treated differently
- Therefore, it is more convenient to refer to mm-wave bands as those of 55 GHz and higher

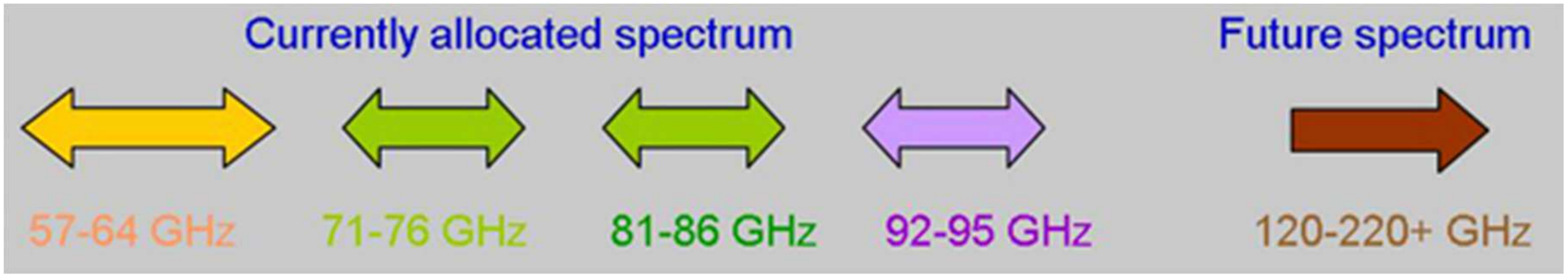


Why Millimetre Waves

- There is interest in the mm-wave and higher frequency bands for ultra high data rate wireless transmission such as GbE and 10-GbE
- To support data rates of 10 Gbps and higher wirelessly, channel bandwidths of many tens of gigahertz will be required, which can be achieved at the mm-waves
- Dedicated wireless systems have fast paybacks, whereas the cost of leasing high-speed fibre services is very high (typical lease costs of 1-GbE services are US$10,000 per month)
- Also wireless is an excellent alternative where fibre is too expensive to lay or cannot be laid without significant disruption or environmental impact

Spectrum for Gigabits Wireless Transmission

- Multi-gigabit data rate millimetre wave networks are becoming viable due to the spectrum allocation and cost reduction in semiconductor devices
- Available bands at mm-wave frequencies
  - 60 GHz
  - 70/80 GHz (E-band)
  - 90 GHz

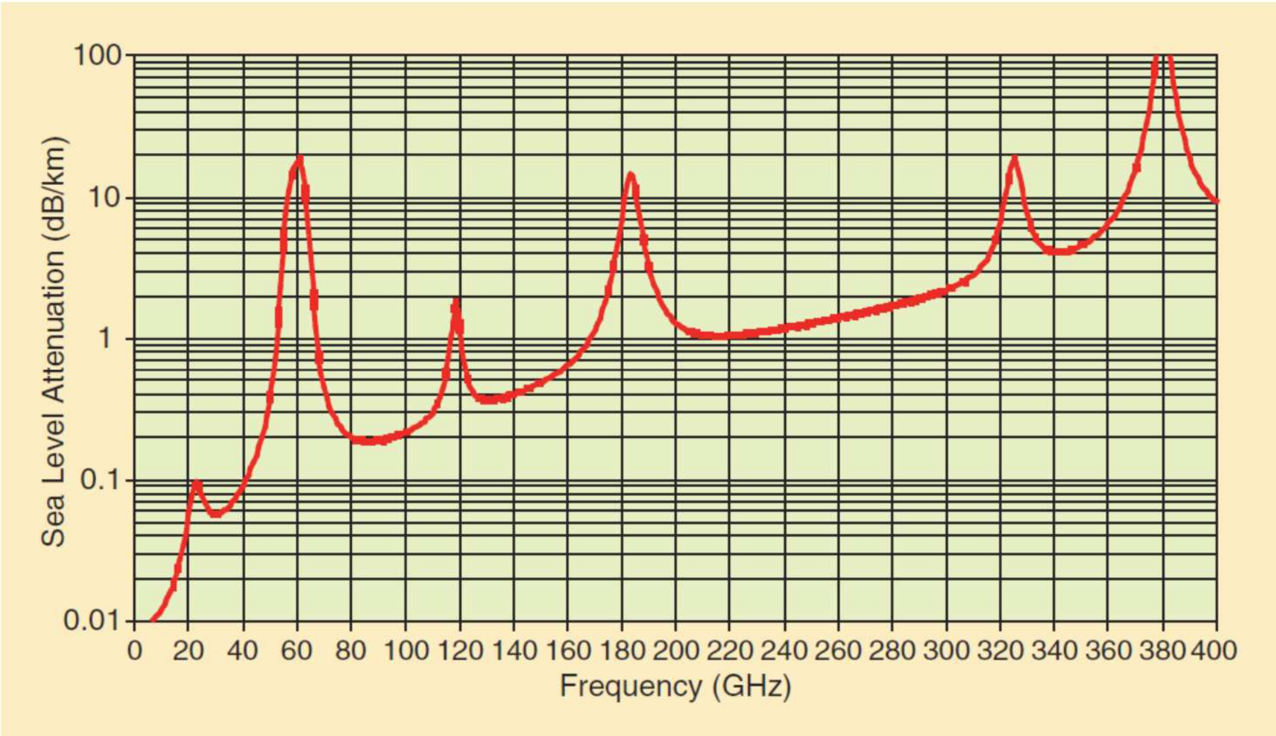


E-Band Spectrum and Channel Sizes

- In the United States, the 71-76 and 81-86 GHz bands are allocated as two pairs of 5 GHz blocks
- No subchannel is defined
- In Europe, 19 250MHz channels are allocated (ITU-R F.2006, March 2012)
  - 125 MHz guard band at two ends of each 5 GHz band
  - Several channel pairing methods are allowed for FDD operation
- In Australia, a band plan similar to United Kingdom is adopted (71.125-75.875 GHz and 81.125-85.875GHz)
- In New Zealand, only 250 MHz, 1.25 GHz, 1.75 GHz, and 2.25 GH channels are permited

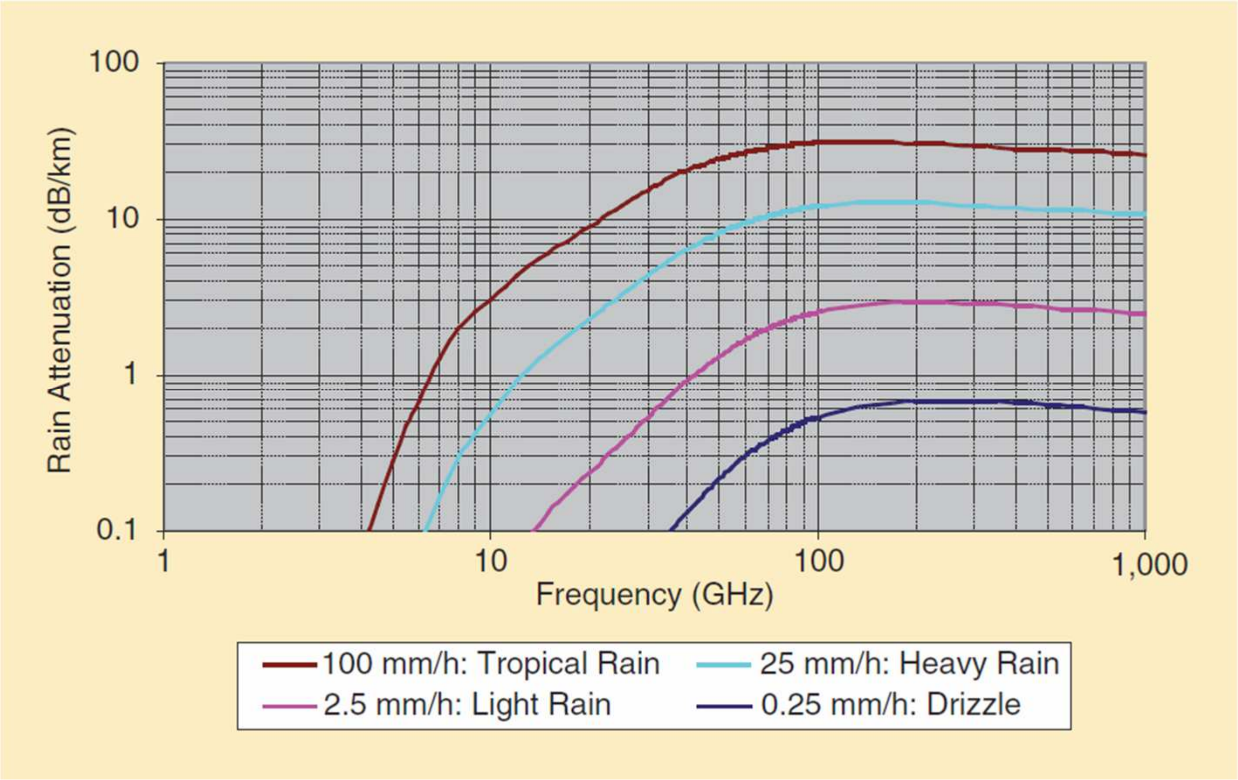
Atmospheric Propagation

- Within so-called atmospheric windows (35, 90, 140, 220 GHz and upwards), attenuation is minimized, allowing superior wireless transmission



Rain Attenuation

- The main factor that limits available communication range at the upper microwave and mm-wave frequencies is the rain attenuation



60 GHz Wireless Systems

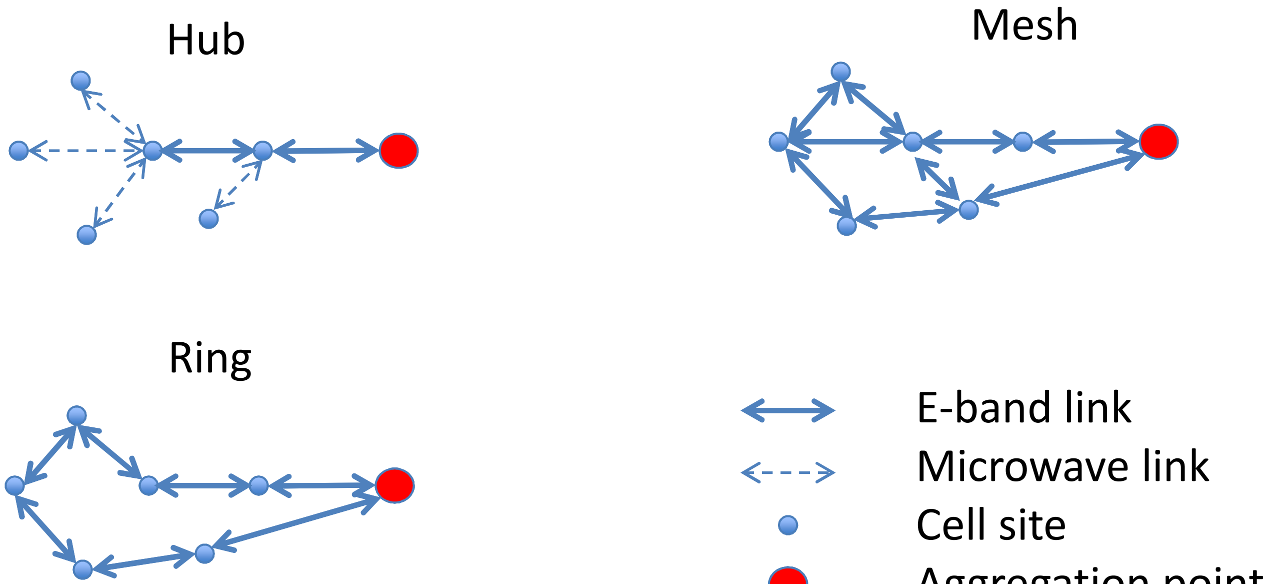
- 60 GHz systems operate at an oxygen absorption peak, reaching a maximum of 15 dB/km absorption at sea level
- Only useful for short-distance transmission
  - 1 Gbps over distances of 400-800 m (outdoor)
  - Up to 4 Gbps over distances of 10 m (indoor) WPAN – WirelessHD, IEEE 802.15.3c
  - Up to 7 Gbps over a short range using approximately 2 GHz spectrum – IEEE802.11ad
- Key benefits of 60 GHz wireless versus other mm-wave technologies
  - Low cost CMOS
  - Radio building blocks such as transceivers, power amplifiers, low noise amplifier, mixers, etc. are more readily available at 60 GHz than the higher mm-wave frequencies

70/80 GHz Wireless Systems

- 70/80 GHz E-bands operate in an atmospheric window where clear air absorption is less than 0.5 dB/km
- However, practical links are much shorter due to rain attenuation (up to 30 dB/km for rainfalls <100 mm/hr)
- Currently available 70/80 GHz equipment can achieve 1 Gbps connectivity with 99.999% weather availability (carrier class performance, equivalent to only 5 min of weather outage per year) over distances of 2-3 km
- Key benefits of 70/80 GHz wireless
  - Unaffected by most other transmission deteriorations (water particles, sand, dust, etc.)
  - Antennas are smaller, portable and can have higher gain
  - Increased frequency reuse and security due to the narrow communication beam and limited radio range

E-band Backhaul Applications (1)

- Cellular and broadband wireless access backhaul
  - IP-based networks require increasingly higher capacity backhaul
  - E-band backhauls can be used to connect cell sites to aggregation points
- Various topologies

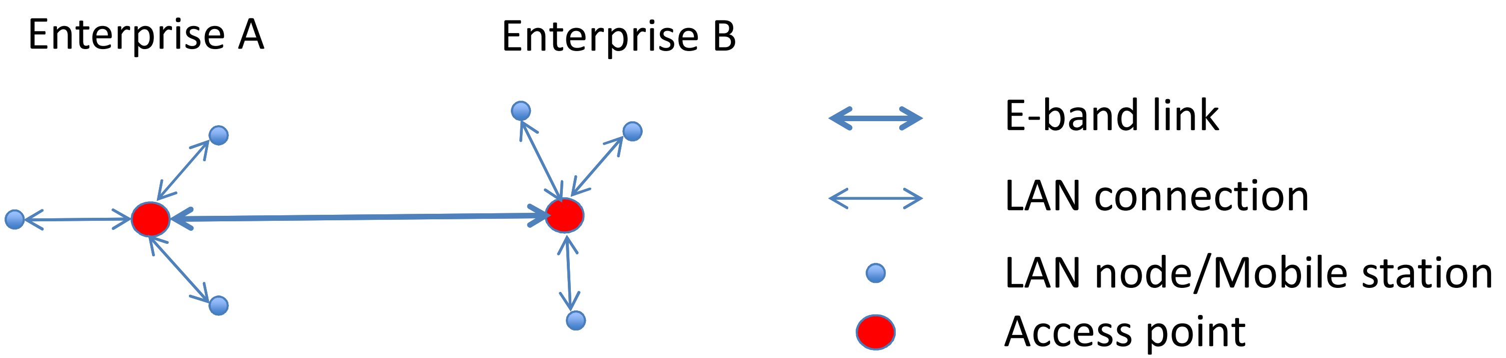


E-band Backhaul Applications (2)

- Distributed antenna system (DAS)
  - With DAS, cellular coverage can be improved by relacing a single antenna at a base station with a number of smaller spatially distributed antennas
  - A radio header (RF transceiver) in DAS is traditionally connected back t base station by fibre optic cable
- There is an opportunity for high speed E-band backhaul to replace the fibre connection

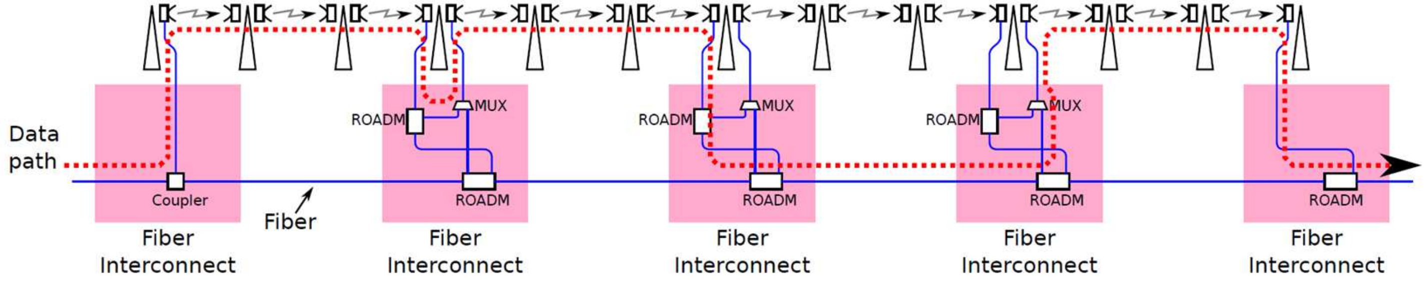
E-band Backhaul Applications (3)

- Enterprise connection
  - Enterprise connectivity refers to the connecting together of businesses, schools, hospitals, campus buildings, and any other enterprise
  - This applications is often called local area network (LAN) extension
- E-band backhaul can be used to provide high speed enterprise connections



E-band Backhaul Applications (4)

- Fibre extensions/backup
  - Fibre optic networks have been the national and international backbone infrastructure
  - However, access to fibre connection may not be available for some locations
  - There is need for short-haul wireless connectivity in the last mile
- E-band backhaul network may provide shorter end-to-end latency than fibre network since radio propagation is faster in the air than in the fibre!



E-band Backhaul Applications (5)

- Other applications
  - Storage area networks (SAN) for machine-to-machine connectivity or backup
  - Portable and temporary links for multimedia transport
  - Military applications
  - …
- Defense Advanced Research Projects Agency (DARPA) 100G program
  - To design, build and test an airborne-based communications link with fibre optic equivalent capacity and long reach that can propagate through clouds and provide high availability
  - Phase 1: Technology development and demonstration
  - Phase 2: System design, integration and test
  - Phase 3: System demonstration

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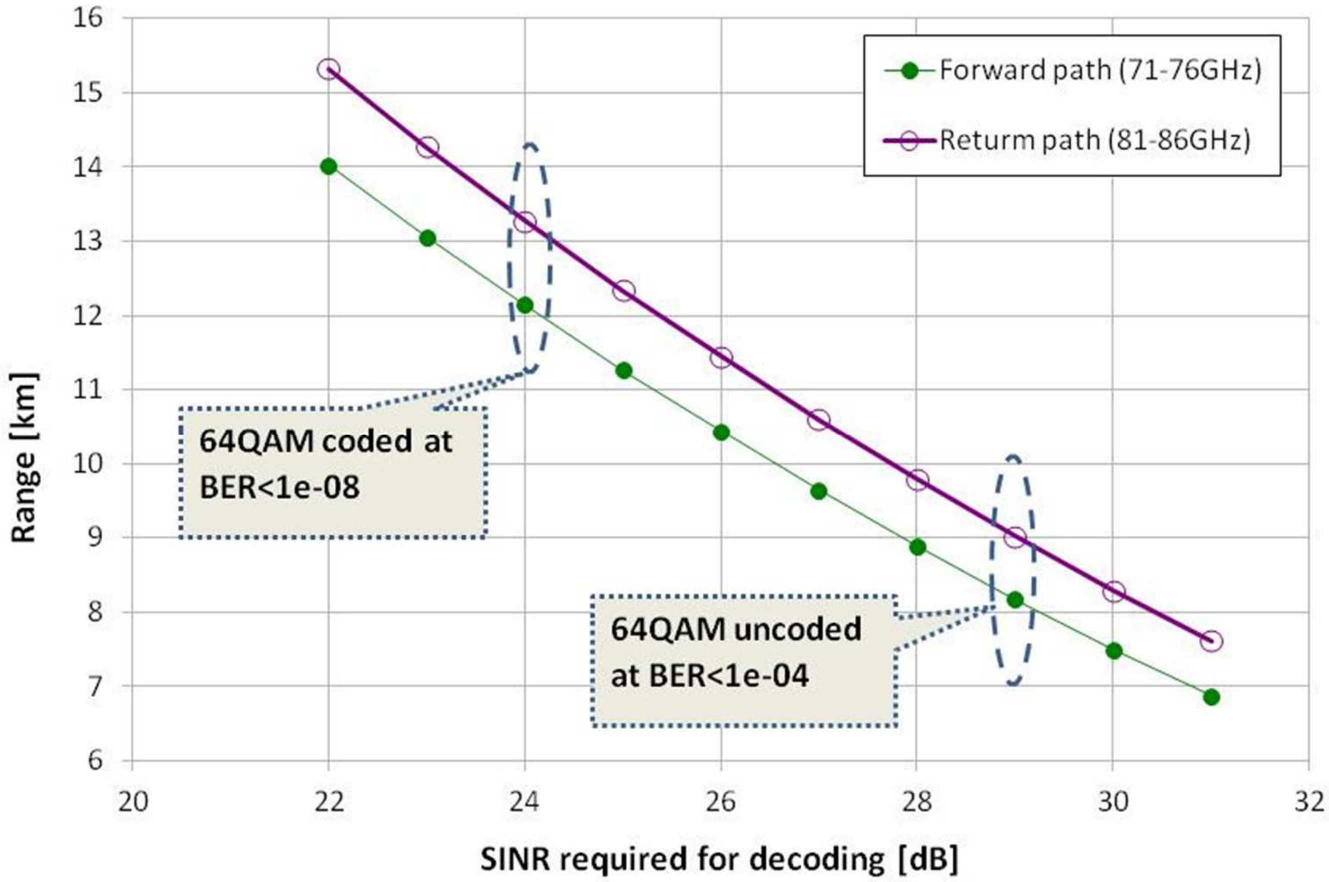
Commercial E-band Systems

- Typically provide up to 1.25 Gbps data rate
  - Using ASK, BPSK
  - Very low spectral efficiency
  - Commercial products available
- Recent developments
  - Direct QPSK SiGe BiCMOS transceiver with up to 9 Gbps data rate – University of Toronto
  - 64 QAM over two 250 MHz channels with up to 2.5 Gbps data rate – Huawei

Typical Link Budget Calculation

	Forward path		Return path	
	Fc [GHz]	**73.5**	Fc{GHz]	**83.5**
Transmit Power [dBm]		**14.0**		**14.0**
P1dB output [dBm]	24		24	
Back-off at 64QAM [dB]	-10		-10	
Less feed loss		**-1.2**		**-1.2**
Transmit Antenna Gain [dBi], 24", 55% efficiency		**50.8**		**51.9**
Tx Antenna Radome loss		**0**		**0**
EIRP [dBm]		**63.6**		**64.7**
Receive Antenna Gain [dBi], 24', 55% efficiency		**50.8**		**51.9**
Rx Antenna Radome loss		**0**		**0**
Rx Antenna pointing loss		**-0.8**		**-0.8**
Rx Loss before LNA [dB] (i.e. diplexer)		**-1.2**		**-1.2**
Rx Bandwidth [GHz]	5		5	
LNA temperature, deg C	35		35	
Thermal Noise in Rx Bandwidth [dBm]	-76.7		-76.7	
LNA Noise Figure [dB]	5		5	
LNA effective input noise [dBm]		**-71.7**		**-71.7**
Implementation loss [dB]		**-4**		**-4**
Total link budget available [dB] (excluding path loss and decoder SINR threshold)		**180.2**		**182.4**

Maximum Range versus SINR



Spectral Efficiency and Distance

- Higher spectral efficiency requires higher-order modulation
- However, there are system penalties
  - Design and implementation cost
  - Reduced receiver sensitivity (higher SNR required)
  - Reduced output power due to linearity in the power amplifier
- The reduction in both transmit power and receiver sensitivity leads to reduced link distance

Spectral Efficiency and Data Rate

- Higher spectral efficiency does not necessarily mean higher data rate
- It also depends on signal bandwidth
- With higher order modulation, the digital modem needs to be implemented by digital signal processing device such as ASIC or FPGA
- However, due to the availability of high speed digital signal processor and mixed signal devices (A/D and D/A), the signal bandwidth cannot be very high
- As a result, the achievable data rate is still low

Data Rate and System Complexity

- To achieve high data rate, channel aggregation is necessary
- However, it adds to system complexity and cost
  - More digital data streams
  - More IF/RF chains
  - Multiplexing and de-multiplexing

Other Practical Limitations

- Antenna
  - Minimum antenna gains are required by regulations (42 dBi in Europe and 43 dBi in US)
  - Antenna diameter has to be > 8 inches (20 cm) and 1 foot (30 cm)
  - Larger antenna is necessary to extend range or give more link margin, but there are limitations in antenna alignment and mounting (towers sway in wind and twist in heat)
- Limited output power (currently 24 dBm at P1dB)
- Analogue filter
  - Narrow Bandwidth and frequency response ripple
- I/Q imbalance
- Phase noise
- Component tolerance and manufacturing fluctuations
- …

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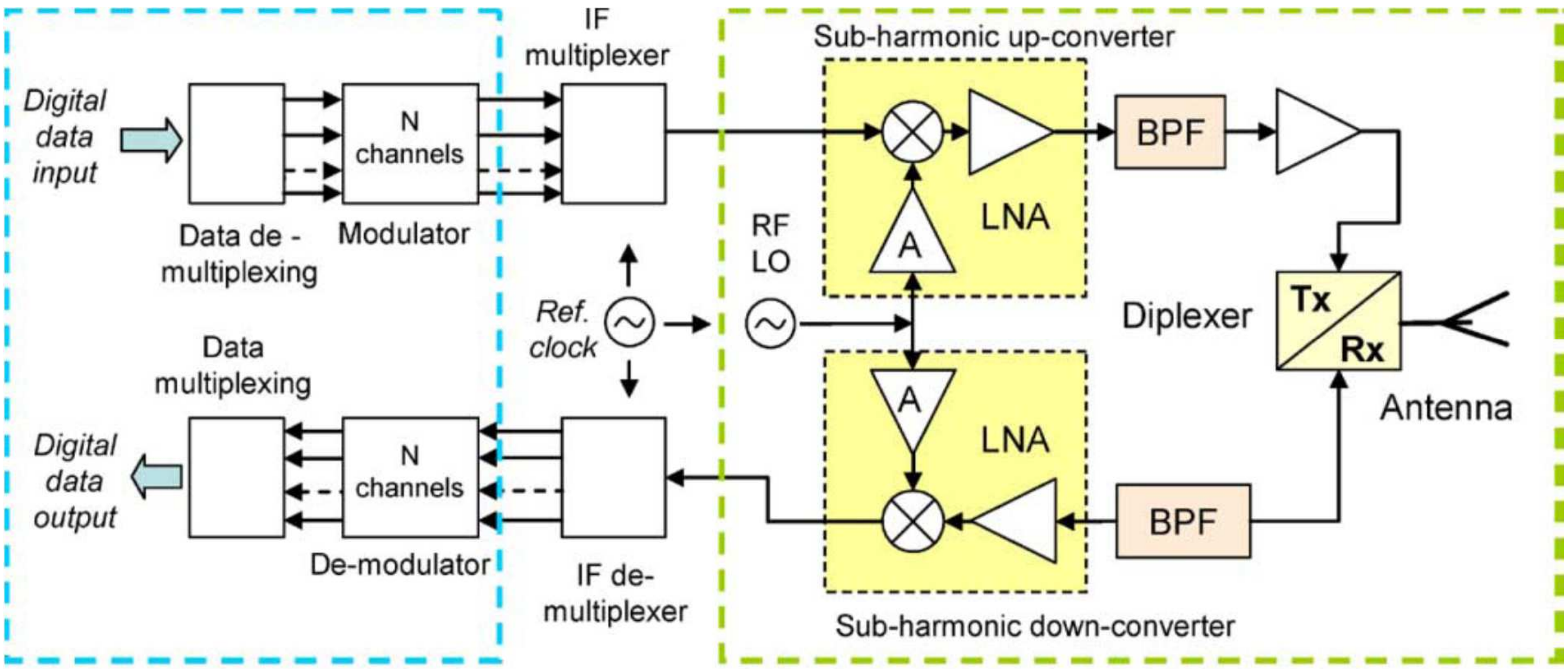
CSIRO 6 Gbps E-band System

- Practical realization of efficient digital modems for mm-wave system is limited by the speeds of analog-to-digital (A/D) and digital-to-analog (D/A) converters available
- Available commercial system has only 0.6 – 1.6 bits/s/Hz spectral efficiency
- CSIRO had developed and demonstrated technologies enabling data rates up to 24 Gbps, the highest speed to date
- Using 8 PSK (phase shift keying) modulation and achieving 2.4 bits/s/Hz spectral efficiency, a 6 Gbps system was demonstrated in 2006

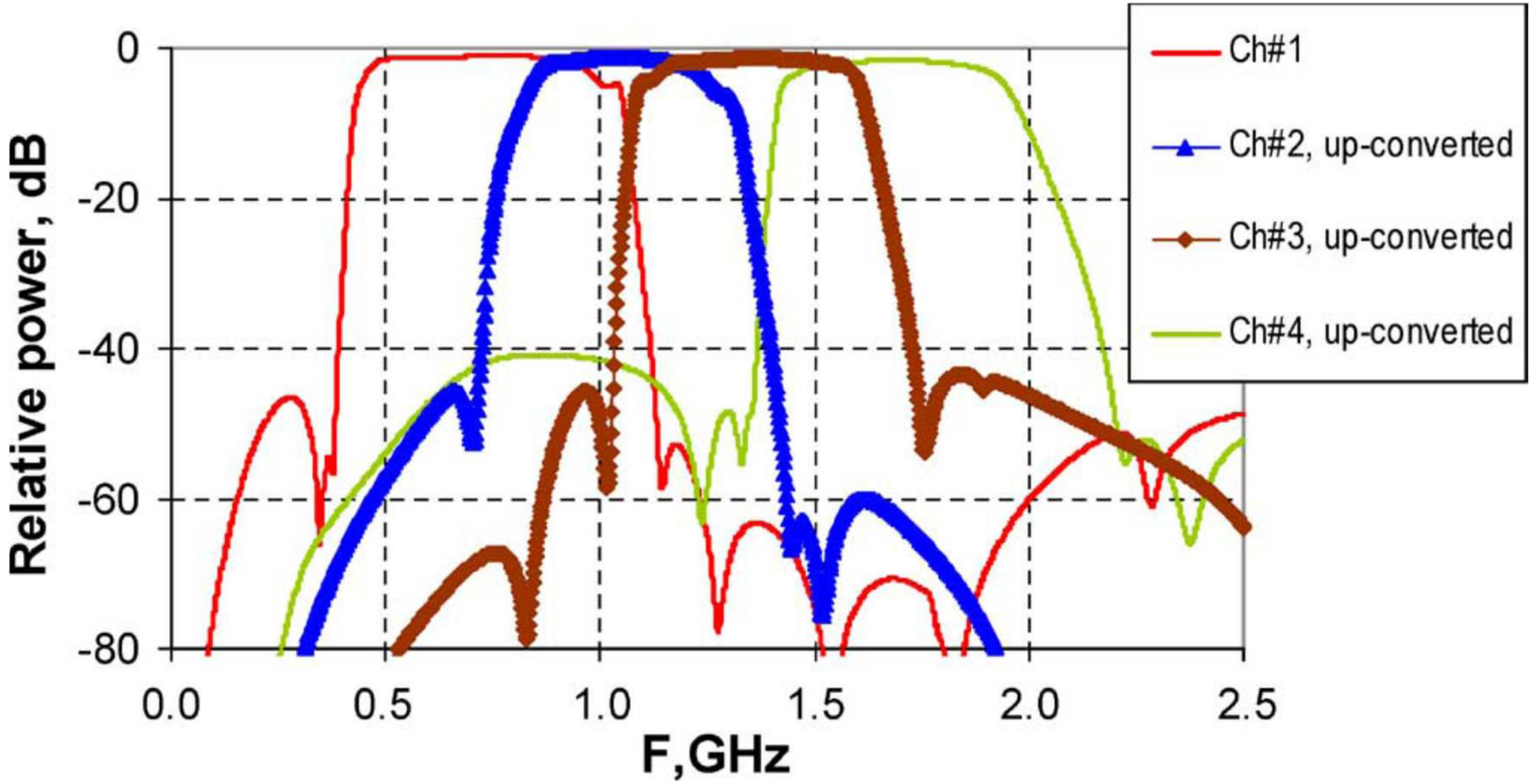
System Architecture

- The system includes a digital interface, a digital modem, an IF module, and a wideband mm-wave front end and a high-directivity antenna



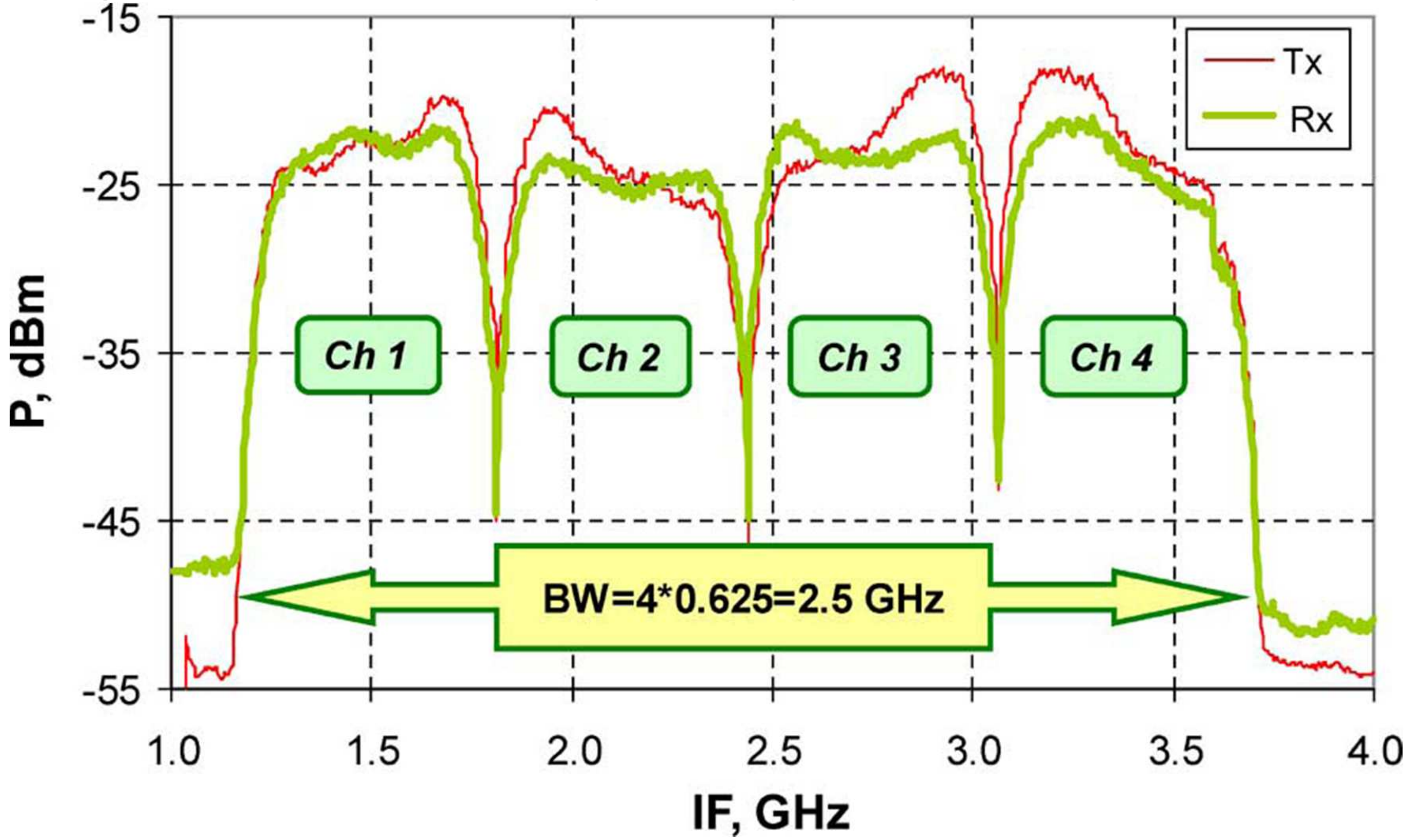
Example of Combining 4 Digital Channels

- Channel 1 is directly generated by RTZ D/A and BPF
- Subsequent channels are up-converted to abut each other

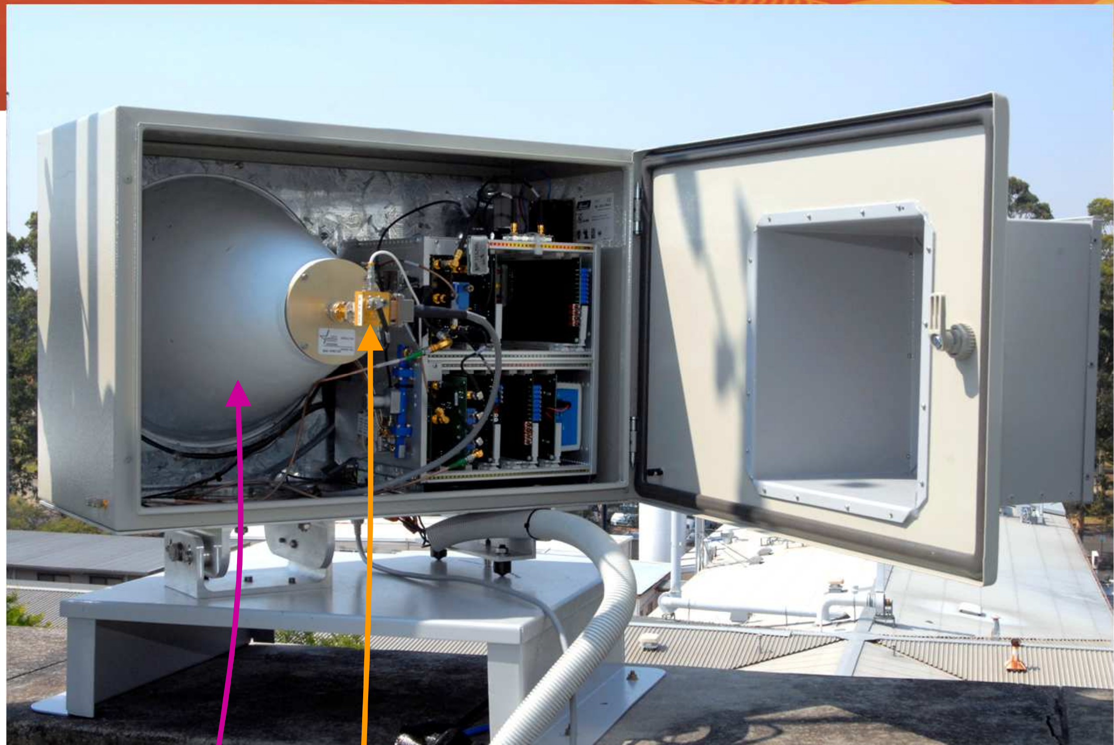


Spectrum of Multiplexed IF Signal

- IF signal at transmitter is pre-compensated



6 Gbps Link Demonstration at Marsfield



Rear View

Conical lens horn antenna

Integrated mmwave front-end

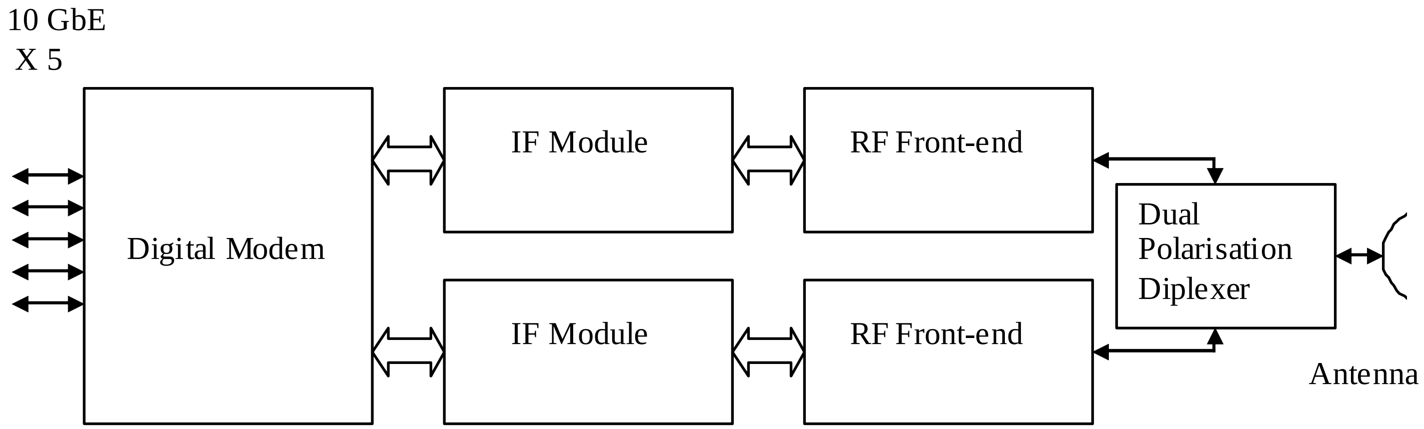
Front View

6 Gbps Link

Other End

Further High Capacity E-band Solutions

- Improve spectral efficiency using higher-order modulation
- Remove guard band/roll-off between sub-channels
- Use dual polarisation
- 50 Gbps symmetric full duplex link can be achieved
- Or asymmetric link with 100 Gbps down link in E-band and 10 Gbps uplink in other mm-wave band



Low Latency and long Range Designs

- CSIRO is currently developing E-band systems which can provide high data rate transmission for multiple purposes
  - Point-to-point full duplex link for short distance low cost high availability applications (scalable data rate up to 10 Gbps)
  - Low latency full duplex relay for long distance fast than fibre applications (5 Gbps)
- Key technologies
  - Cross layer design to remove unnecessary buffering
  - Pre-equalisation to reduce receiver side signal processing latency
  - Low PAPR transmission to improve power efficiency
  - High performance FEC to improve receiver sensitivity

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Further Improvements

- Possible higher order modulation
  - 256QAM has been implemented in CSIRO Ngara Microwave Backhaul (10 Gbps)
  - Possible to be applied to E-band system
- LOS MIMO
  - Use multiple antennas to further improve the capacity (DARPA 100G program TA2)
- Improving link availability and distance for mm-wave systems
  - Automatic transmit power control (ATPC) which is widely used in microwave radios but has not been widely adopted in mm-wave systems; Adaptive coding and modulation (ACM), Adaptive rate; ...
- Long range mm-wave link using smart antennas
  - Increase transmit power with antenna array and digital beamforming

Conclusions

- The availability of the 10 GHz spectrum in E-band provides an opportunity for high capacity wireless link, ideally suited for fibre replacement and backbone networks
- However, there are significant technical challenges such as how to achieve higher spectral efficiency and extend operating range
- CSIRO has solutions to tackle these challenges and is developing the most advanced E-band systems for high capacity wireless applications

Thank you

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