Empowered by Innovation NEC

mmWave Technology
Enabler High-Density High-Capacity Radio

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Outline

- Drivers for ever growing demand for Capacity
- Evolved Network Requirements - towards 10Gbps radio at affordable TCO
- Need for a New Radio Technology
  - Evolution on Modulations and Throughput
  - Approach to 10Gbps Radio
- 10Gbps radio in E-Band
  - Analysis and Capabilities of E-band
- Vision of the iPASOLINK series
- Next Challenges for Future System
- Conclusion

Drivers for ever growing demand for Capacity

Mobile networks applications

- LTE-Advanced Aggregation 1Gbps/ch
- Front-haul CPRI 2.5/5/10Gbps for LTE

Other applications

- High Capacity for Event (ENG)
  - Non-compressed image transmission HD-SDI Signal (N x 1.5Gbps/ch)
- Disaster Recovery(Disaster Relief System)
  - Emergency backup for public communications
- High Capacity Link in urban area, backup for Fiber Link
- Fiber Spur Extension
  - Metro Ring where fiber is not available

HD-SDI: High Definition Serial Digital Interface
CPRI: Common Public Radio Interface

Evolved Network Requirements - towards 10Gbps radio

Why and where is 10Gbps radio required?

- The demands for over 1Gbps radio have been increased in many scenes, mobile network, broadcasting, back up for fiber link, etc.
- The required capacity is going to reach to 10Gbps. However, today there is no commercial radio equipment which has such high capacity.
- If 10Gbps capacity can be achieved, it can cover almost all of the demands.
  - It is available for “Low Latency Application”.
  - The users can connect 10Gbps Ether signal to it directly without concern for QoS control.
  - It will be possible to achieve high capacity applications which cannot be available without a fiber optic today.
  - Also it will help to reduce the digital divide.
  - TCO must be maintained as low as possible

Conventional Radio Transport Technology and its Capability

	MicroWave Up to 42GHz	MillimeterWave 60GHz	MillimeterWave E-band
Max CS	56MHz	1000MHz	1000MHz
Standard Modulation	256QAM	QPSK	QPSK
Multiplexing	Dual pole	None	None
Capacity/CS Typ.	700Mbps	1Gbps	1.2Gbps
Efficiency Typ.	12.5bps/Hz	1bps/Hz	1.2bps/Hz
Capacity/CS Limit	2Gbps *1	2.4Gbps *2	2.4Gbps *2

***1:112MHz CS, 2048QAM**
***2:Dual pole multiplexing without XPIC**

Need for a New Radio Technology

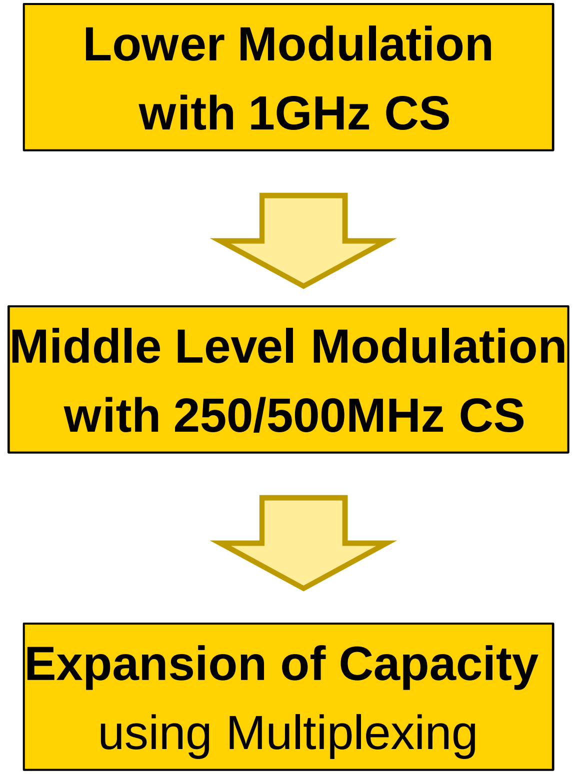
These technologies are required in the following order of increasing complexity.

1. Wide-band
   - N x 50MHz CS is available in V-band(60GHz).
   - N x 250MHz CS is available in E-band.

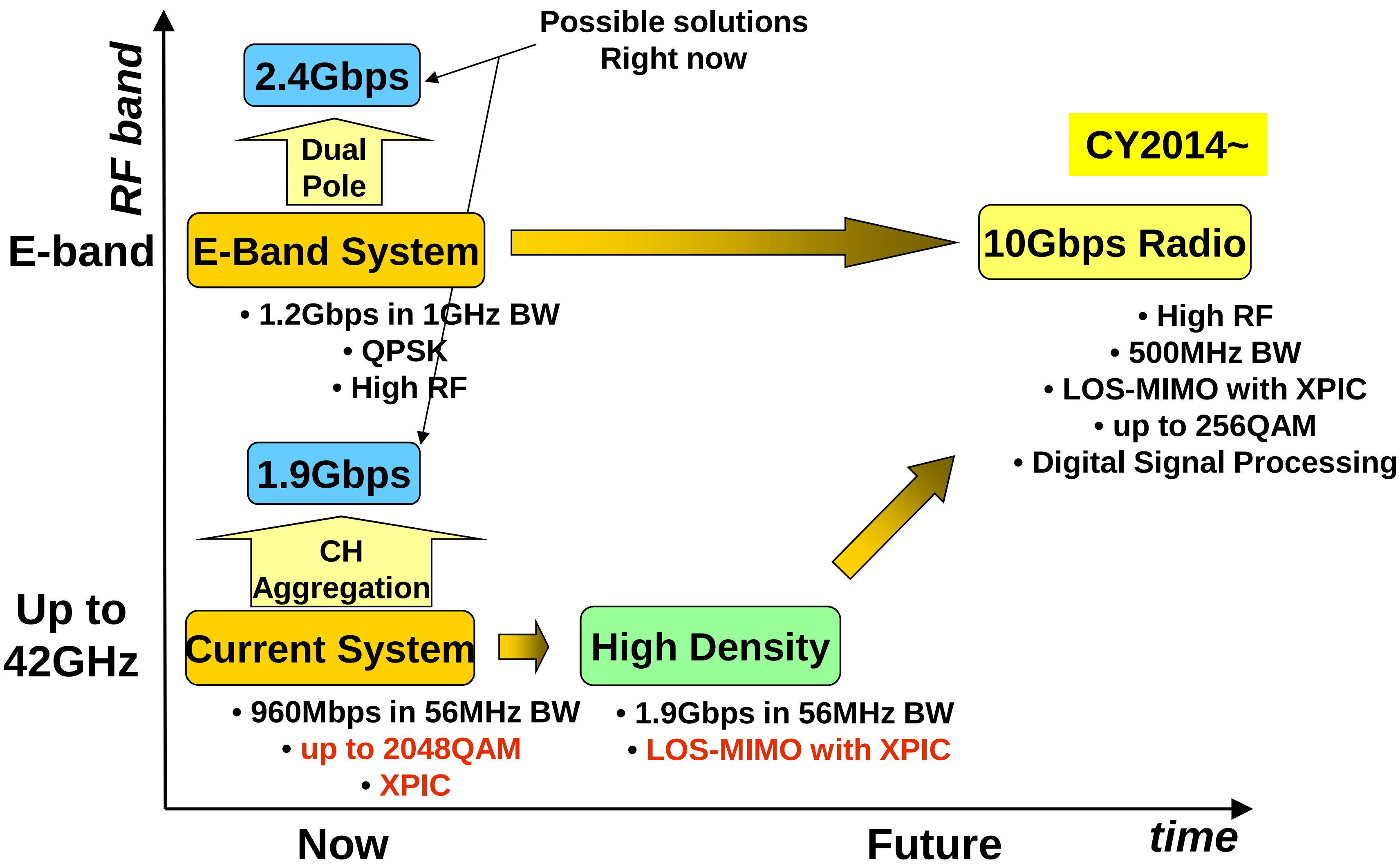
2. Multi-Level QAM
   - High Efficiency can be achieved.
   - High Speed Digital Signal Processing is required.

3. Dual Polarization Multiplexing
   - XPIC is necessary for QAM.

4. Spatial Multiplexing
   - LOS-MIMO can achieve double capacity.



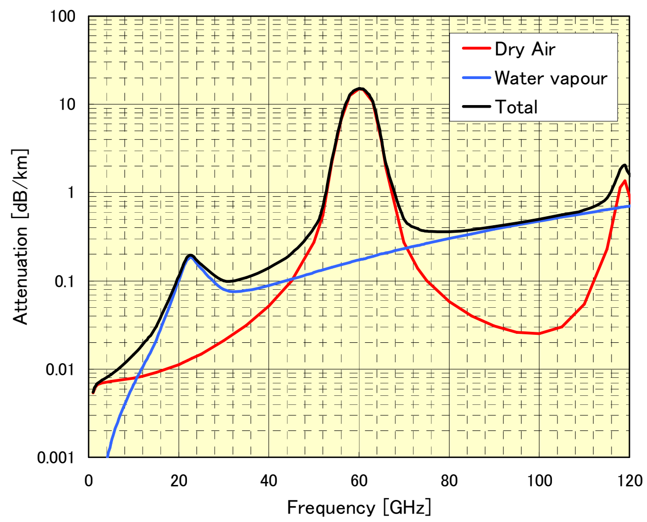
Evolution on Modulations and Throughput



Propagation Characteristics of MillimeterWave

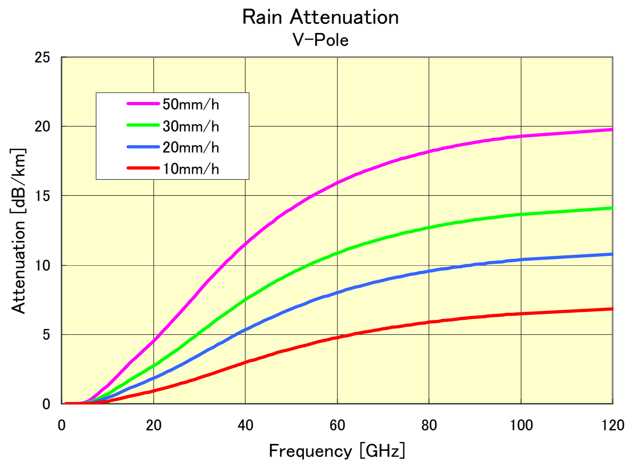
High Attenuation by atmospheric gases

- 60GHz has large attenuation.(15dB/km)
- The loss in E-band is relatively small.



High Attenuation by rain fall

- Higher frequency has larger attenuation.
- The link distance of millimeterwave is restricted by this attenuation.



High Free Space Loss

$$FSL\,[dB] = 92.45 + 20\log(d \cdot f)$$

where, d:distance[km], f:frequency[GHz]

Approach to 10Gbps Radio

Option 1 Applying Higher Level QAM in Conventional System

Assuming 56MHz CS with Dual pole

- 2^{100}QAM is necessary. Obviously impossible!
- 112MHz CS can increase the capacity only double. 2^{100}QAM ➡ 2^{50}QAM
- Adding LOS-MIMO can increase the capacity only double. 2^{50}QAM ➡ 2^{25}QAM
- This consideration suggests that 10Gbps in under 42GHz band is impossible.

Option 2 Wide-band 128QAM in E-band

- 1600Mbaud is necessary.
  - It is difficult for the current DSP & Data Converter.
  - SNR degradation due to wide BW should be considered.
- 2GHz CS is required for only one link.
  - Even in E-band, the available BW is only 5GHz for one direction.

Option 3 Introducing LOS-MIMO

- 256QAM with 350Mbaud, 128QAM with 400Mbaud are enough.
- This is the only practical commercial solution today.

Performance Comparison

Below are the performance comparison between Option 2 and 3.

- **Option 2 : Wider bandwidth instead of LOS-MIMO**
- **Option 3 : Adding MIMO, to reduce the signal BW**

	Option 2-1	Option 2-2	Option 3
Modulation	128QAM	128QAM	128QAM
Symbol Rate	1600Mbaud	800Mbaud	400Mbaud
Multiplexing	Non	Dual Pole (XPIC)	Dual Pole (XPIC) + Spatial (MIMO)
Channel Separation	2GHz	1GHz	500MHz
RSL Improvement	0dB (Reference)	3dB (BW 1/2)	9dB (BW 1/4 + SD)
Difficulties	High speed DSP & Low SNR	High speed DSP	Multi antennas
Expectation in the future	Breakthrough in DSP	Breakthrough in DSP	All-in-one

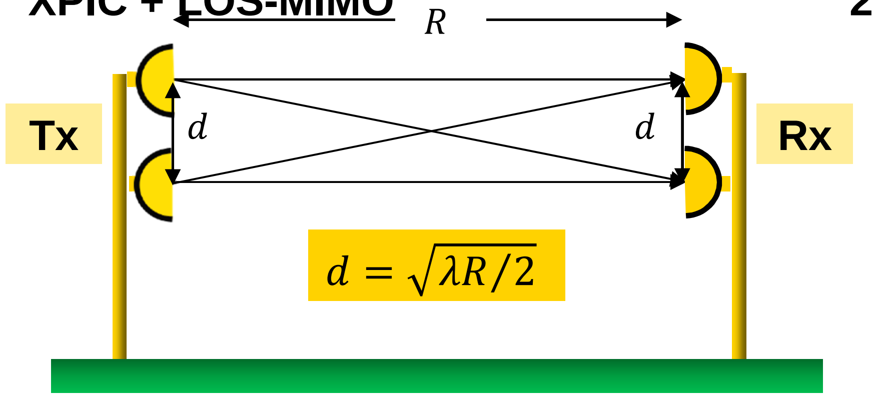
10Gbps Radio in E-band

Combining advanced technologies is required.

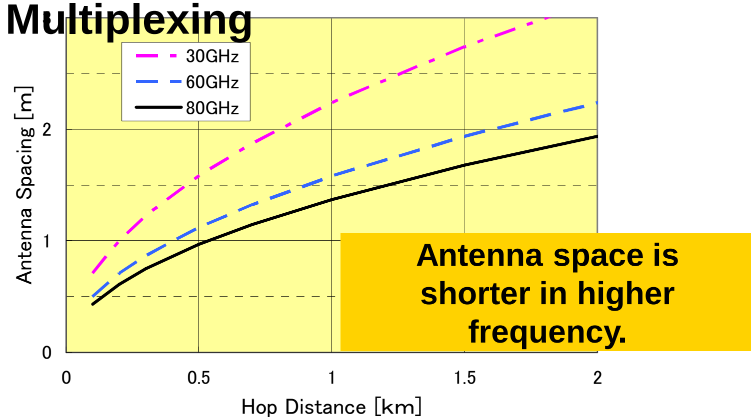
- Optical Digital Coherent Detection System up to 100Gbps has been realized.
  However, this system requires special and very expensive components.
- 10Gbps Radio System has to be "appropriate price", using commercial-grade devices.
- Latest FPGA has achieved up to around 400MHz in DSP operational speed.
  Assuming this speed limit, Dual pole multiplexing is not enough even applying 1024QAM.
- Introducing Spatial multiplexing, 10Gbps Radio System becomes realistic.
- Wide bandwidth requires High frequency band, it is convenient for LOS-MIMO technology.

One possibility is

- 128QAM, 400Mbaud in 500MHz CS   2.5Gbps/carrier
- XPIC + LOS-MIMO   2 x 2 Multiplexing



System Image



Hop Distance vs. Antenna Space

Example of Link Budget Calculation

Conditions

- Modulation QPSK
- Channel Sepa. 1GHz
- Antenna 0.3mφ
- Tx PWR 10dBm
- Hop Distance 2km

①EIRP	**+53.0dBm**
②Loss	**137.3dB**
	↓
③RSL	**-41.3dBm**
C/N	**37.4dB**
④RequiredC/N	**14.0dB**
	(BER 1x10^{-6})
⑤Fade Margin	***23. 3dB***

Item	Value	Unit
Transmitter Power, Pt	10.0	dBm
Tx Antenna Gain, Gt	43.0	dBi
Effective Radiated Power, EIRP ①	53.0	dBm
RF Frequency, fo	80.0	GHz
Distance	2.0	km
Gas Attenuation ②	0.40	dB/km
Free Space Loss, FSL	136.5	dB
Rx Antenna Gain, Gr	43.0	dBi
Received Signal Level, RSL ③	-41.3	dBm
Noise Figure, F	7.0	dB
Bandwidth, fs	650.0	MHz
Noise Power, N	-78.7	dBm
Required C/N ④	14.0	dB
Receiver Threshold @1E-6	-64.7	dBm
Fade Margin ⑤	23.3	dB

Calculation method of Availability

Recommendation ITU-R P.530-13

Propagation data and prediction methods required for the design of terrestrial line-of-sight systems

1. Rain rate of time rate 0.01% $R_{0.01}$(ITU-R P.837)
2. Attenuation rate γ[dB/km] (ITU-R P.838)
3. Effective distance d_{eff}[km] (ITU-R P.530)
4. Attenuation rate at time rate 0.01% $A_{0.01}$ $A_{0.01} = \gamma d_{eff}$
5. Attenuation rate of time rate p% A_p using $A_p = A_{0.01} \cdot 0.12\, p^{-(0.546+0.043\log p)}$
6. Fade margin from Link Budget
7. Time rate p which has same attenuation as the Fade margin
8. This p is the outage, then Availability is 100-p[%].

An example of calculation is shown in the next slide.

Note: The above method is guaranteed only up to 40[GHz].

New ITU specification for propagation data and prediction methods need extension to higher frequency

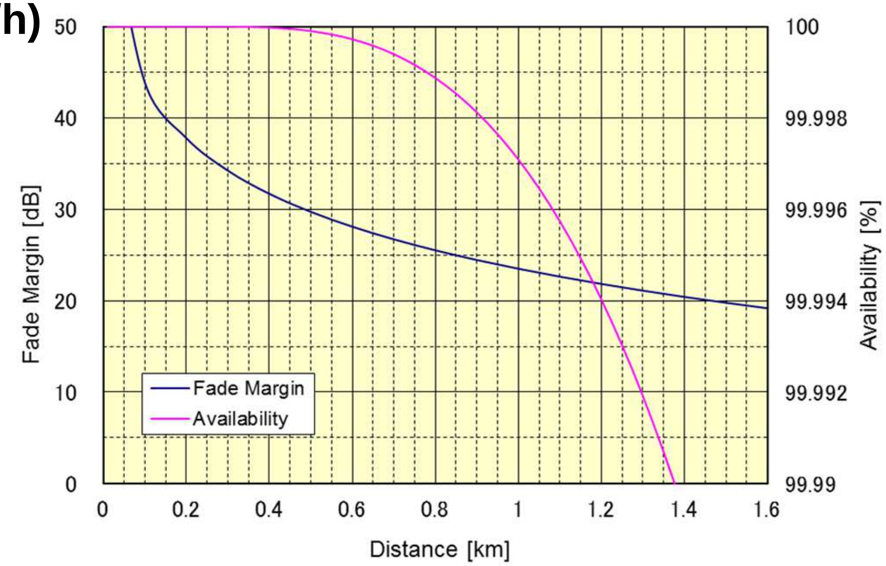
Analysis and Capabilities of E-band

Assumptions

Modulation & Coding	LOS-MIMO 128QAM, RS code
Symbol Rate	400Mbaud
CNR @1e-6	27dB (Coding Gain=4dB, Degradation=1dB)
Antenna	D=0.3m, 45dBi
Tx Power	+12dBm (OBO=11dB, w/o DPD)
NF	12dB
Phase Noise Effect	Negligible small
Gas Attenuation	0.4dB/km
Rain Zone	K (42mm/h)

Results

RSL threshold	-49dBm
System Gain	61dB
Hop Distance for 99.99%	1.4km



NEC mmWave Solutions

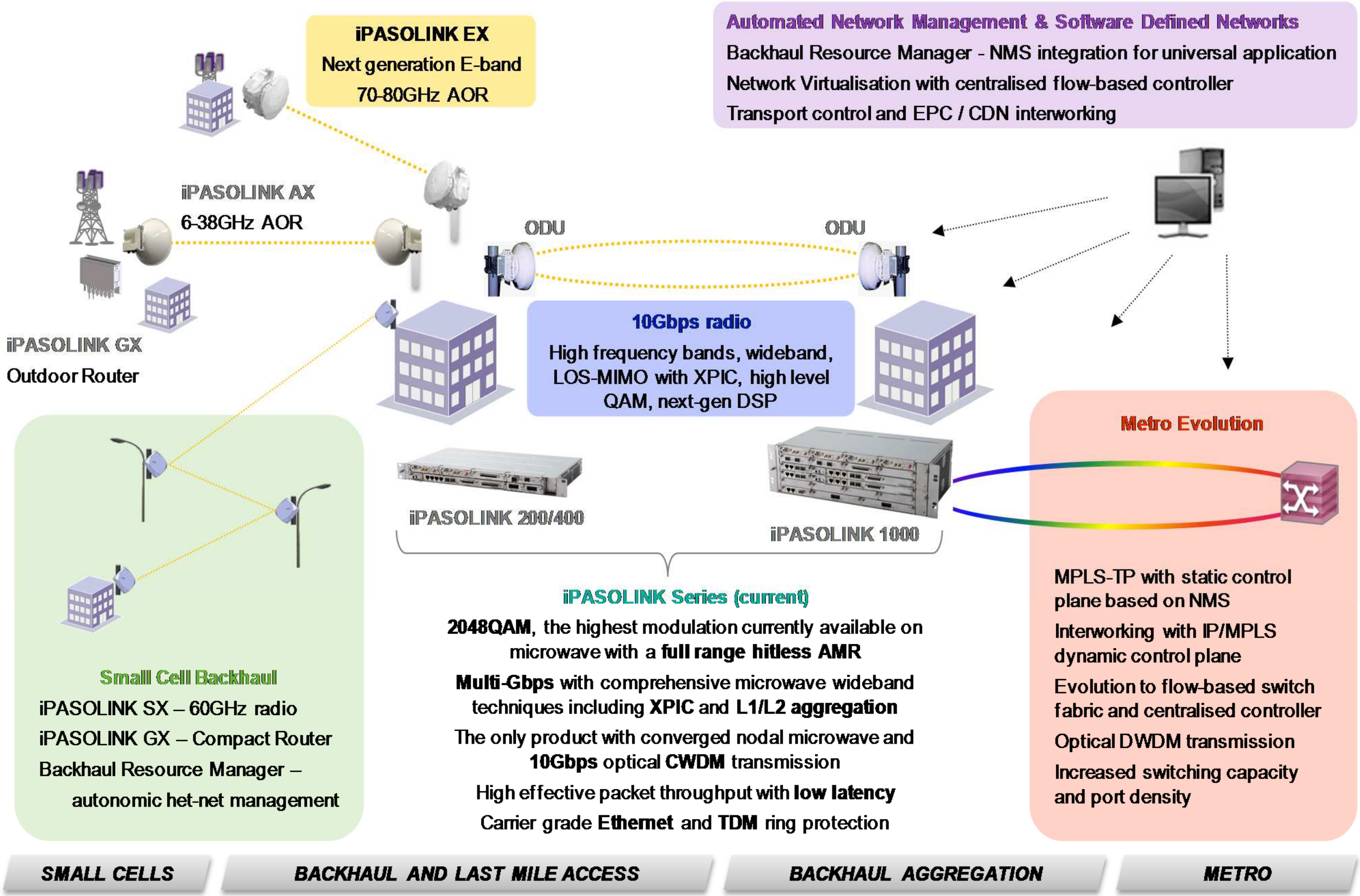
iPASOLINK SX for urban street-level connectivity

- 60GHz (V-band) compact high-capacity all-outdoor radio, currently being evaluated by 5 major network operators in Europe.
  Commercially available from second quarter of 2013.

iPASOLINK EX for urban small cell traffic aggregation and distributed RAN 'fronthaul'

- New 70-80GHz (E-band) all-outdoor radio capable of delivering capacities in excess of 10Gbps, commercially released at the time of this year's Mobile World Congress and preselected for deployment by two major pan-European network operators.

Vision of the iPASOLINK series



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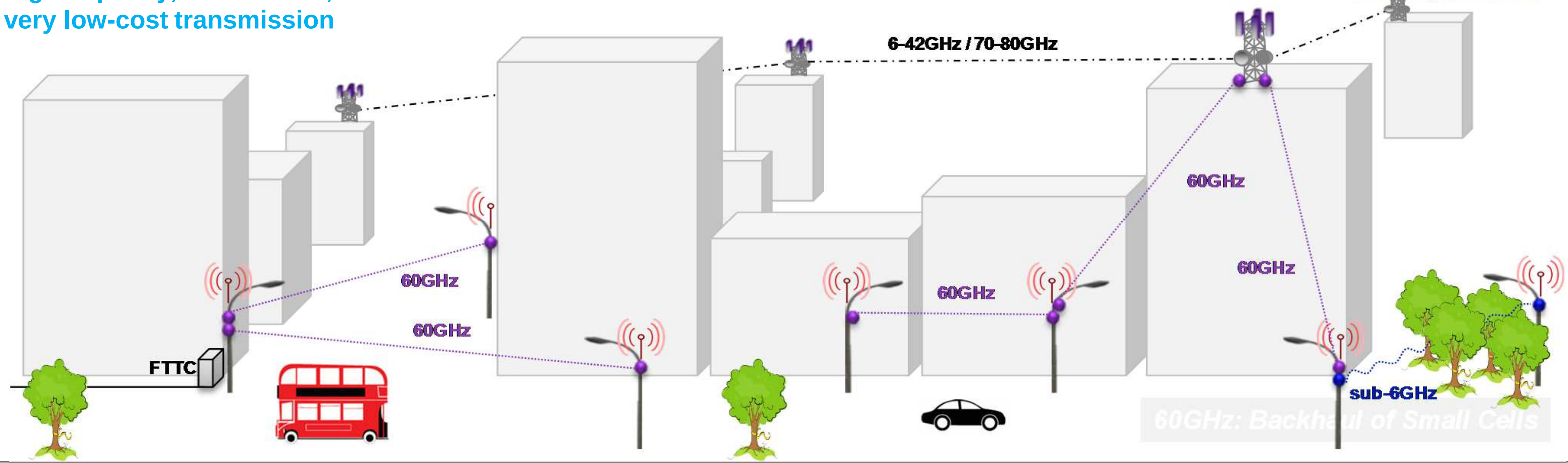
NEC's AOR types and Usage

	iPASOLINK AX 6-38GHz	iPASOLINK SX 60GHz 57-66GHz	iPASOLINK EX 70-80GHz 71-76GHz and 81-86GHz
Single channel link capacity vs link reach	up to 500Mbps many kilometres	up to 200Mbps up to 1km	up to 6.4 Gbps and higher up to 3km
Spectrum availability and licensing	up to 56MHz channels, scattered always fully licensed – high cost occasionally congested	~9GHz contiguous mostly unlicensed – zero cost occasionally light licensed	2 x 5GHz mostly light licensed – lower cost occasionally fully licensed
Physical size of the equipment	compact (all-outdoor) antenna diameter 30/60cm	very compact (all-outdoor) antenna diameter ~12cm	compact (all-outdoor) antenna diameter 20/30/60cm

6-38GHz/60GHz/70-80GHz: (Macro Cell) Backhaul and Aggregation

60GHz is ideally suited for roof-to-street or street-to-street deployments with its high-capacity, short-reach, very low-cost transmission

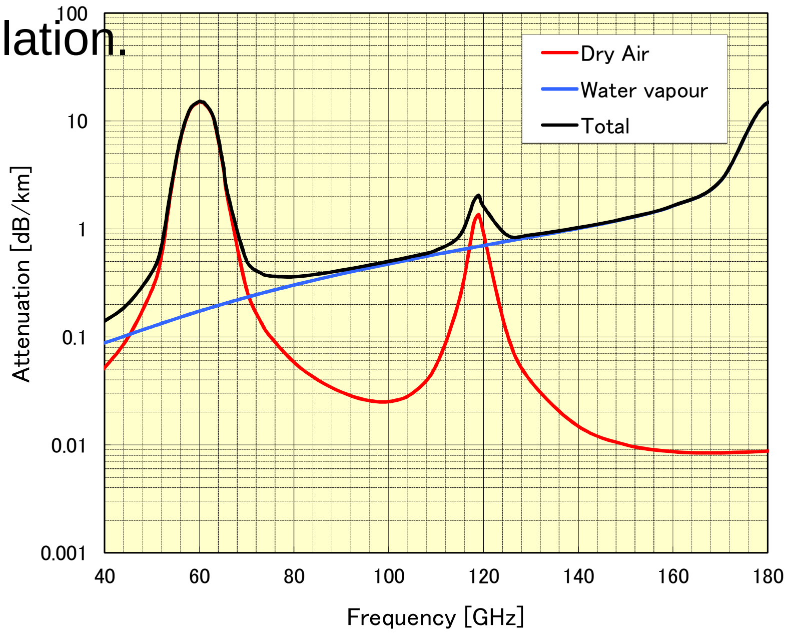
6-38GHz and 70-80GHz suit rooftop and mast deployments with higher capacities and more 'robust' network planning and operations



Next Challenges for Future System

Frontier band - 120GHz

- Total BW is more than 10GHz.
  - In Japan, 116 - 130GHz is open.
- Wide band occupation is still allowable.
  - . 10Gbps = QPSK x 5Gbaud for FDD
- Attenuation due to gas and rain are slightly larger than E-band.
  - Restriction for link distance can be compensated by using lower modulation.
- Cost reduction and downsizing can be achieved.
  - Simple MODEM and small antenna.



Conclusions

- The demands for high capacity transmission have been increased in many scenes.

- MillimeterWave is well suited for such demands due to its wide-bandwidth.

- Using multiplexing technologies, 10Gbps can be achieved with high efficiency and high performance.

- Over 100GHz bands have possibilities for further high capacity.

NEC Group Vision 2017

To be a leading global company leveraging the power of innovation to realize an information society friendly to humans and the earth

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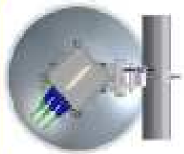
NEC Solution Toolkit for Small Cell Backhaul

- NEC offers focused portfolio of products to address the challenges of small cell backhaul:

iPASOLINK SX

- Compact all-outdoor **60GHz radio**
- 50MHz channels (FDD)
- AMR from QPSK to 256QAM
- Capacity up to 330Mbps (at 440m)
- Link distance up to 980m (at 82Mbps)
- Low cost, simple I&C procedures

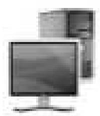


iPASOLINK EX

- All-outdoor **70-80GHz radio**
- 50/250/500MHz channels (FDD)
- AMR from QPSK to 256QAM, XPIC
- Capacity up to 1600Mbps (at 1.6km)
- Link distance up to 3km (at 400Mbps)
- Capacity roadmap up to 12Gbps

iPASOLINK GX

- Compact **all-outdoor L2/L3 router**
- Switching capacity 12Gbps
- 6 GE ports, 4 of which PoE supply
- Packet QoS, OAM & Sync
- Low cost local aggregation and mesh



Resource Assistant

- Software based **OAM&P assistant**
- Computes optimal backhaul paths
- Driven by SLA policies, e.g. capacity
- Paths executed in existing NMS
- Fully controlled by the operator

- Further additions to the solution portfolio are under consideration, subject to customer requirements and market trends:

Sub-6GHz radio
Licensed NLOS links for 3G / WiFi cells

Next-generation PON
Highly re-configurable PON at low cost

Resource Manager
Resource Assistant with added dynamic path implementation

NEC's High-Value Approach to Small Cell Backhaul

iPASOLINK SX is the market changing 60GHz product

- 50MHz channels increase interference-free frequency re-use in dense deployments
- LTE-ready, spectrally efficient high capacity, up to 256QAM with adaptive modulatio
- Very cost competitive, designed specifically for requirements of small cell backhaul

iPASOLINK EX sets the new benchmark for high-performing E-band radio

- Innovations in DSP, ultra wideband modem, RF devices and RF power amplifiers
- High capacity roadmap up to 12Gbps with introduction of XPIC and LOS-MIMO

iPASOLINK GX for a novel approach to intelligent networking

- Low cost enabler of mesh and partial mesh topologies for differentiation in network
- Award winning product: "Best of Show" award at the Interop exhibition, Japan, June

NLOS and Optical technologies integrated into common OAM framework

- Best-of-breed NLOS products complementing millimetre wave for coverage gaps
- Simple PON architecture supports low cost complementary use of Optical in access

Resource Manager can significantly ease the burden of OAM&P

- Calculation algorithms for optimal path provisioning developed by NEC research lab
- Outputs based on SLA objectives: capacity, latency, cost, power consumption, etc.