GNSS MEASUREMENT ENGINE SYSTEM DESIGN: COMMUNICATION ENGINEERING PERSPECTIVES

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ERLANG NETWORK BRINGS A NEW DIMENSION INTO GNSS POSITIONING ENGINEERING

- We combine professional grade satellite positioning, DSP & Big Data techniques together with cloud computing.
  - High-performance satellite positioning based on cloud computing is fundamental for IoT location based services
- The salient features include:
  - **instant response (cold start less than 1s),**
  - **improved accuracy (10x),**
  - **increased sensitivity (10x),**
  - **reduced BOM (40%),**
  - **higher power efficiency (90%),**
  - **OTA upgradable**
  - And, of course, enhanced security and privacy.
- Our technology can replace or be complementary to existing device-based GPS solutions.
- All these are essential to and highly demanded by many 5G, logistic, IoT, children safety and senior care services

KEY GNSS MEASUREMENT ENGINE DESIGN PARAMETERS

1. **Sensitivity and Link Budget**
   - a signal processing perspective. Link budget and mutual coupling between receiver and transmitter
   - an information theory perspective. communication in low-SNR region.
2. **Accuracy (Error) Budget**
   - spatial channel models
3. **Battery Life and Energy (Power) Budget**
   - comprehensive energy modelling

LINK BUDGET AND EXAMPLES: GPS, LTE AND OTDOA

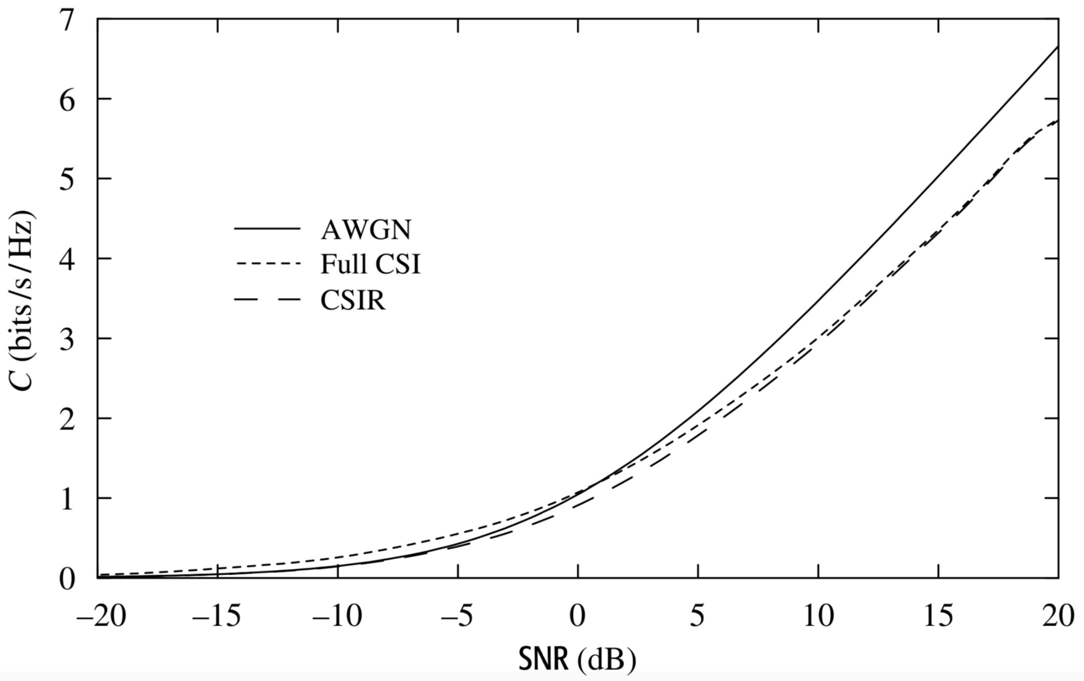
Parameter	GPS	LTE, 10MHz	LTE OTDOA	Comment
Transmitter Power	44.3 dBm	typical 46 dBm	additional power boost	
Transmitter Antenna Gain and Cable Loss	10.2~12.3 dBi	16 dBi		
Target Propagation Path-Loss	183 ~ 189.8 dB	e.g., 3GPP TS 25.996 modified COST231		
Cochannel Interference Margin		3 dB		Margin for inter-cell interference when the device is on the cell edge.
Fast Fading Margin		4 dB		Typically it is set to be about 4 dB.
Antenna Efficiency		4.7 dB		
RFIC Noise Figure		2.8 dB		
Thermal Noise Floor		107.3 dBm		
Body Loss				usage model dependent

GNSS MEASUREMENT ENGINE: A SIGNAL PROCESSING PERSPECTIVE

	Reference	ULPC Mode	HP Mode	
Signal Power at antenna port	-150			dBm
C/N0 at IF	23.9 = - 150 + 173.9			dB-Hz
IF Bandwidth	3.0			MHz
IF SNR	-40.9 = -150 - (-109.1)			dB
	Coherent Processing			
Sample Rate	2.046	4.092	4.092	MHz
Ideal Coherent Gain	43.5	46.5	54.7	dB
Implemt. Losses	-3.1	-3.5	-1.6	dB
Actual Coherent Gain	40.5	44.1	54.1	dB
SNR	-0.43	3.18	16.22	dB
	Non-Coherent Processing			
Squaring Loss	-1.69	0.93	5.1	dB
Processing Gain	45	45	25	
Non-coherent Gain	19.6	19.6	16.6	dB
Final SNR	14.3	16.5	22.0	dB

Frank van Diggelen, *A-GPS: Assisted GPS, GNSS and SBAS*, Artech House, April 30, 2009

LOW SNR REGIME: A INFORMATION THEORY PERSPECTIVE (1/2)



$$C = \mathbb{E}[\log(1 + |h|^2 \mathsf{SNR})] \approx \mathbb{E}[|h|^2 \mathsf{SNR}] \log_2 e = \mathsf{SNR} \log_2 e \approx C_{\text{awgn}}$$

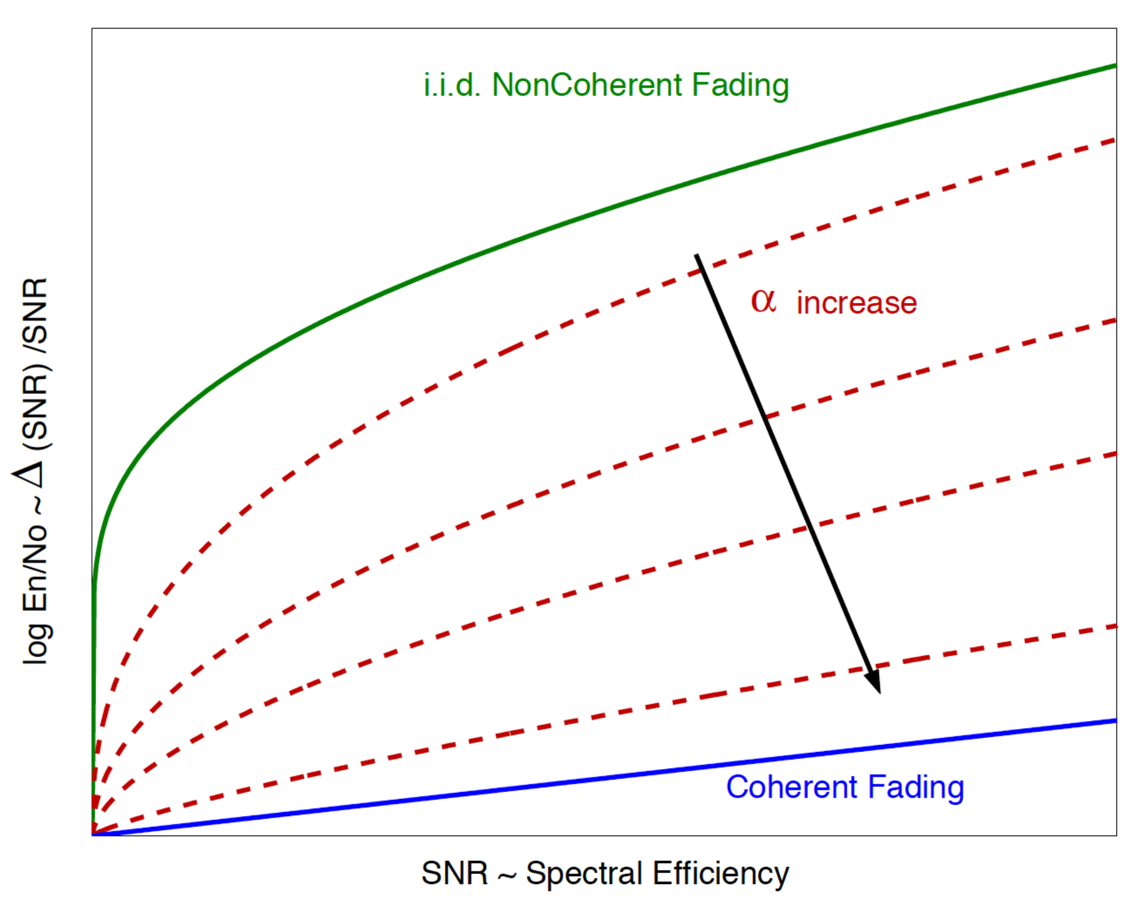
D. Tse and P. Viswanath, *Fundamentals of Wireless Communication*, Cambridge University Press, 2005

- At low SNR regime, the Jensen's loss becomes negligible and the capacities become approximately linear.
  - The reliable rate supported by the AWGN channel is much more sensitive to the received SNR at low SNR than at high SNR
- At low SNR regime, the impact of fading is very significant.
  - For reasonably small outage probabilities, the outage capacity is only a small fraction of the AWGN capacity at low SNR

LOW SNR REGIME: A INFORMATION THEORY PERSPECTIVE (2/2)

$$\lim_{\text{SNR}\to 0} \frac{C_{fading}(\text{SNR})}{\text{SNR}} = \lim_{\text{SNR}\to 0} \frac{C_{\text{AWGN}}(\text{SNR})}{\text{SNR}} = 1$$

- Bad News: "Channel capacity in the limit of vanishing SNR per degree of freedom is known to be linear in SNR for fading and non-fading channels, regardless of channel state information at the receiver (CSIR)."
- Good News: "although a near linear capacity can be achieved in both cases eventually at low enough SNR, this limit is approached much more slowly for the non-coherent case."



L. Zhang, D. Tse and M. Medard, *Channel Coherence in the Low SNR Regime*, IEEE Trans. Information Theory, vol. 53, no. 3, pp. 976-997, March 2007

ERROR SOURCES FOR OTDOA SYSTEMS

Error Sources	GNSS Positioning	LTE OTDOA
transmitter clock	1.5 m	15 m
transmitter antenna coordinate error or satellite orbit error	2.5 m	< 3 m
ionospheric & tropospheric delays	5.5 m	N/A
signal measurement accuracy	0.3 m	40 m when SINR > -13 dB
multipath excess delay	0.6 m	30 m in suburban
GDOP		0.9

Sources: Trimble, Novatel and Qualcomm

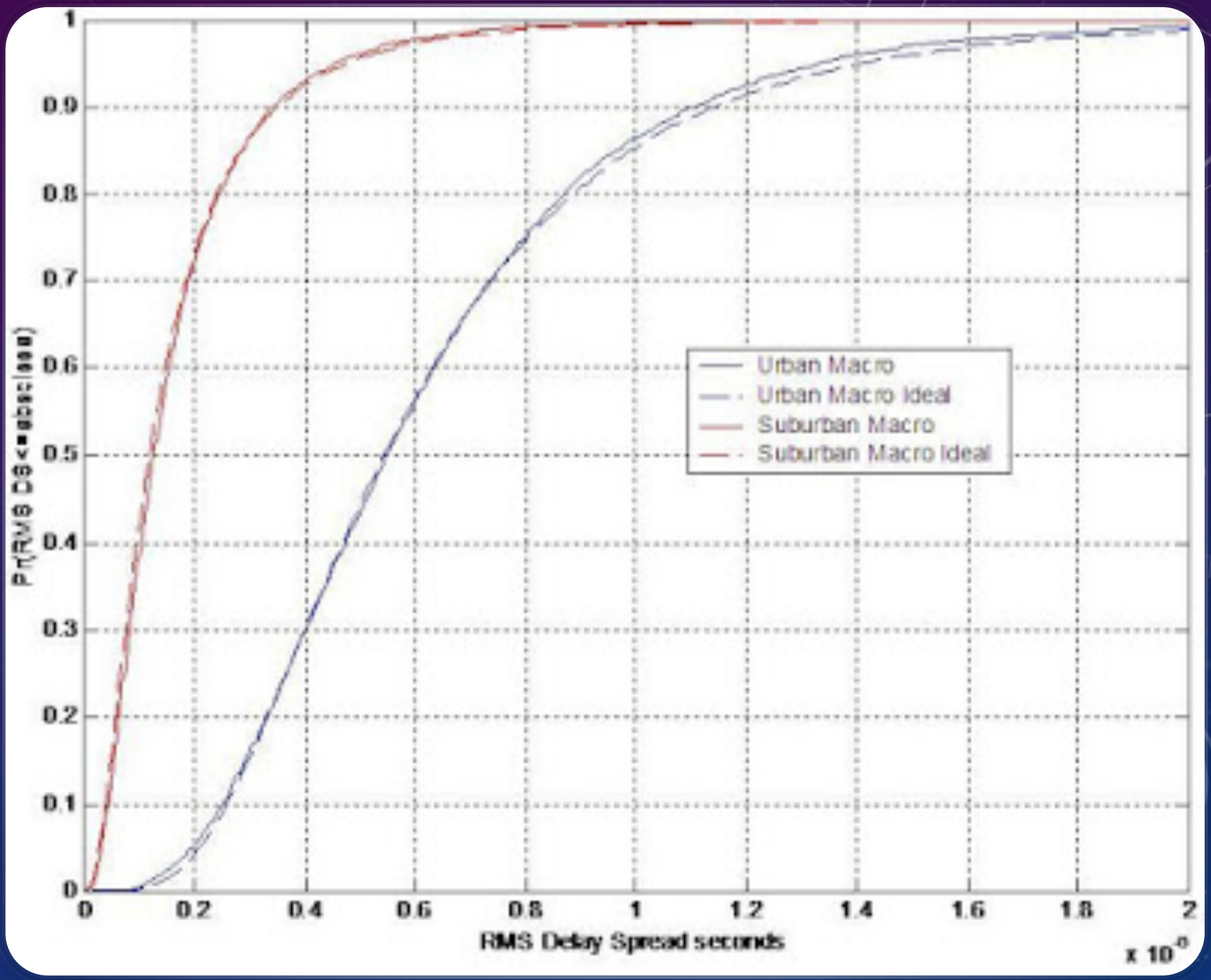
ACCURACY BUDGET EXAMPLE

Error Sources	Absolute GPS		Differential GPS	
	P Code	L1 C/A Code	P Code	C/A Code
Satellite Clock & Ephemeris Errors	3.9	3.9	0	0
Ionospheric Delay	3.1	9	0	0
Tropospheric Delay	2.0	2.0	0.15	0.15
Receiver Noise and Resolution	1.1	11.1	1.1	11.1
Multipath	**1.2**	**12**	**1.2**	**12**
Other			0	0
***Selective Availability**		30	0	0
Total System Error 1σ	5.6	35.6	1.3	16
Position Error PDOP = 2.92	**16.3 m**	**104 m**	**3.8 m**	**48 m**

R. M. Kalafus, Vilcans, N. Knable, “Differential operation of Navstar GPS”, Navigation Vol. 30, No. 3, 1983

MULTIPATH DELAY SPREAD

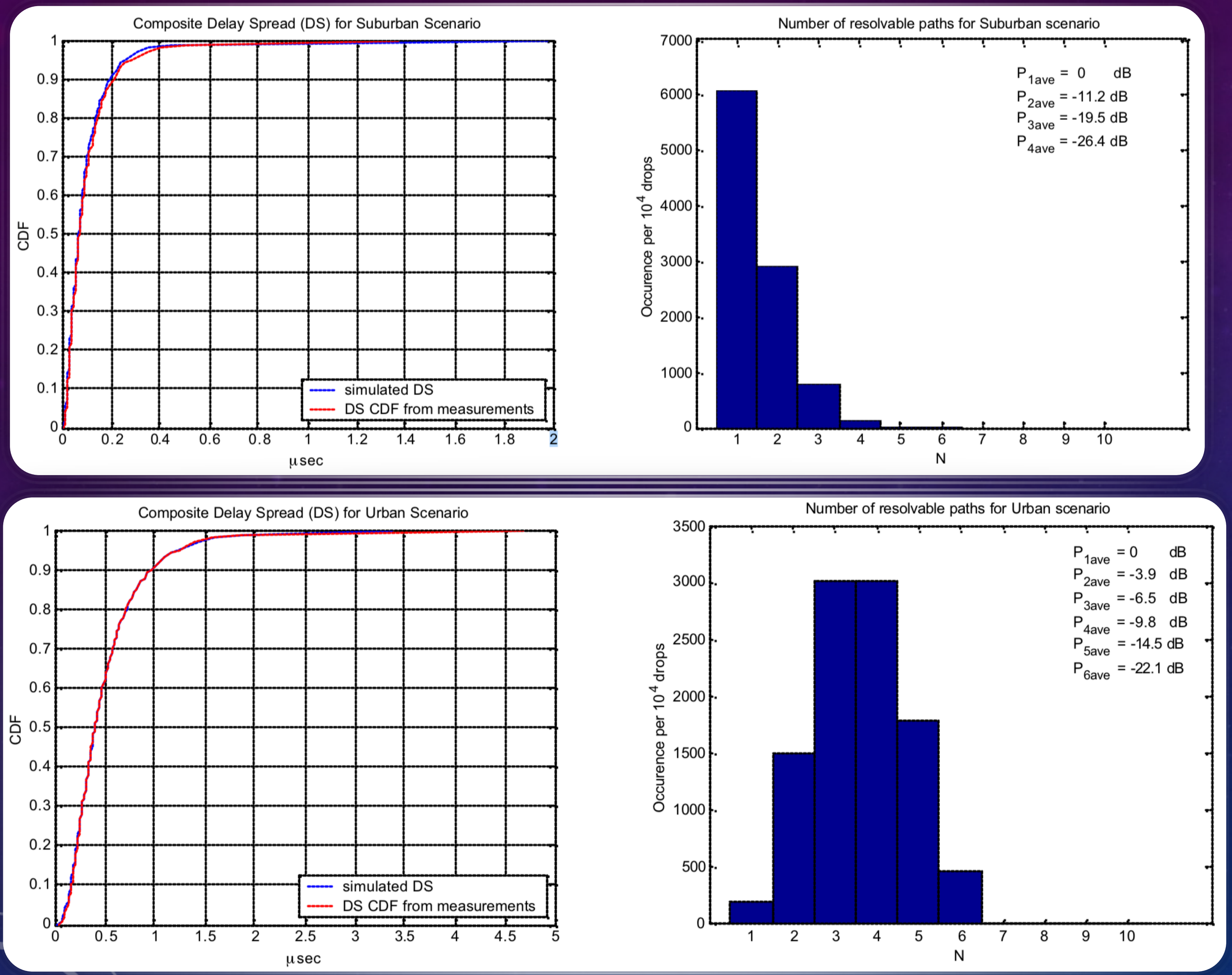
- In [1], Sousa, et. al., reported the 90th percent rms delay spread to be 1.2 µs in suburban Toronto.
- In [2], Ling, et. al. observed that the 90th percent rms delay spread was 1.7 µs in Lakehurst NAES, New Jersey.
- In [3], Baum reported the 77th percent rms delay spread was 1 µs, the 94th percent rms delay spread was 2 µs in Rolling Meadows, Chicago.



[1] E. Sousa, V. Jovanovic, C. Daigneault, “Delay spread measurements for the digital cellular channel in Toronto”, IEEE Trans. on Vehicular Technology, Nov 1994

[2] J. Ling, D. Chizhik, D. Samardzija, R. Valenzuela, “Wideband and MIMO measurements in wooded and open areas”, Lucent Bell Laboratories,

[3] K. Baum, “Frequency-Domain-Oriented Approaches for MBWA: Overview and Field Experiments”, Motorola Labs, IEEE C802.20-03/19, March 2003

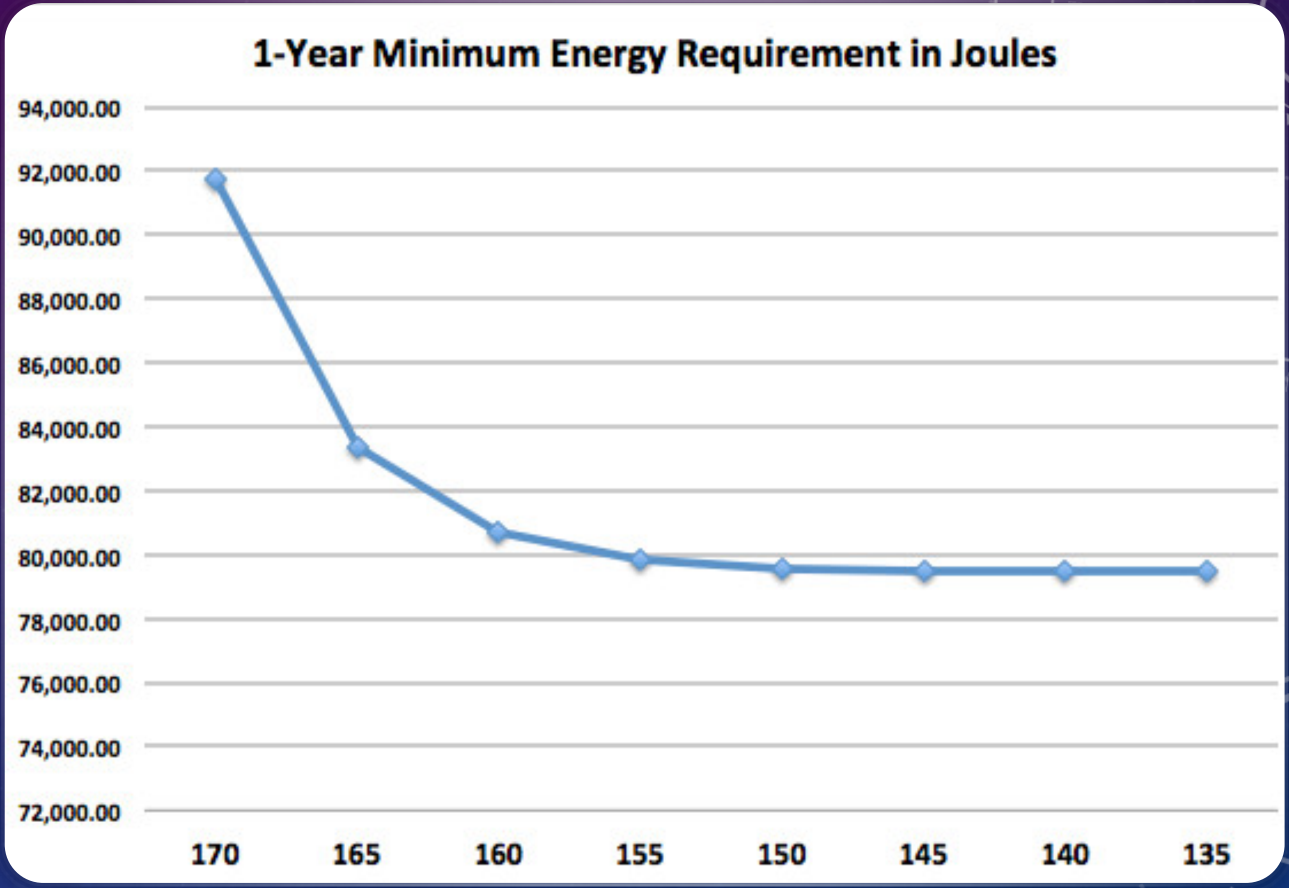


STATISTICS FOR 3GPP/3GPP2 MACRO CHANNELS

- 3GPP & 3GPP2 system level assumptions
- The Chip rate is 3.84Mcps.
- Only the paths with power higher than –15dB relative to the strongest path are recorded.
- The shown statistics are the non-power weighted ones

ENERGY BUDGET

- Energy Budget models how much energy is consumed in each stage of the total process, particularly considering L1 signal processing and L2 protocol stack.
- It is no surprising that for many wireless system, there are tradeoffs between energy budget and link budget, sensitivities, response time, battery life, etc.



EXAMPLE: LTE STATE MACHINE FOR ENERGY MODELLING AND BATTERY LIFE ESTIMATION

Parameters	Values	Unit
Number of PDSCH subpackets	3.00	
Transmission and Reception Time per PDSCH subpacket	1.00	mili-second;
PDSCH Decoding Time Per subpacket	0.0714	milli-second; 1 LTE subframe
ACK/NAK delay per subpacket	3.00	mili-second;
NAK/ACK Transmission Time per subpacket	1.00	mili-second;
Subsquential Subpack Transmission Delay	3.00	mili-second;
Total Reception, Decoding and Acknowledging Time	21.00	mili-second;
Energy Consumption per Paging Message (PDSCH) Reception, Decoding and Acknowledging	5,615.21	micro-joule;
Time interval Per PRS Power Measurement	2.00	subframes
Number of Cells	5.00	
Energy Consumption per OTDOA Measuremet	3,222.00	micro-joule; (XO+SX+RFIC+BB) x Measuring Interval
Total Energy Consumption per OTDOA Fix	54,260.00	micro-joule;

ENERGY MODELLING EXAMPLE

- GPS RF Power: 39.6 mw
- Deep-Sleep: 25 uw
- Micro-Sleep (XOSC+RSX+CLCKGEN): 44.6 mw
- Active (XOSC+RSX+CLCKGEN+1xRx): 101.4 mw
- BBIC PLL Power: 0.5 mw
- BBIC PLL warm-up: 3ms
- LTE Baseband: 200 mw
- Tx PA: 1000 mW in average
- Battery: shelf time, engineering loss, power supply efficiency, headroom, etc.

THANK YOU VERY MUCH FOR YOUR TIME!