

Network Design Considerations and Deployment Concerns for a Ground Aircraft Communication System

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Presenter



Leonhard Korowajczuk

- CEO/CTO CelPlan International
- 45 years of experience in the telecom field (R&D, manufacturing and services areas)
- Holds13 patents
- Published books
 - "Designing cdma2000 Systems"
 - published by Wiley in 2006- 963 pages, available in hard cover, e-book and Kindle
 - "LTE, WiMAX and WLAN Network Design, Optimization and Performance Analysis"
 - published by Wiley in June 2011- 750 pages, available in hard cover, e-book and Kindle
- Books in Preparation:
 - LTE , WiMAX and WLAN Network Design, Optimization and Performance Analysis
 - second edition (2012) LTE-A and WiMAX 2.1(1,000+ pages)
 - Network Video: Private and Public Safety Applications (2013)
 - Backhaul Network Design (2013)
 - Multi-Technology Networks: from GSM to LTE (2014)
 - Smart Grids Network Design (2014)















CelPlan International

- Employee owned enterprise with international presence
 - Headquarters in USA
 - 450 plus employees
 - Revenues of US\$ 40M
 - Twenty (20) years in business
- Subsidiaries in 6 countries with worldwide operation
- Vendor Independent
- Network Design Software (CelPlanner Suite)
- Network Design Services
- Network Optimization Services
- Network Performance Evaluation

- Services are provided to equipment vendors, operators and consultants
- High Level Consulting
 - RFP preparation
 - Vendor interface
 - Technical Audit
 - Business Plan Preparation
 - Specialized (Smart Grids, Aeronautical, Windmill, ...)
- Network Managed Services
- 2G, 3G, 4G, 5G Technologies
- Multi-technology / Multi-band Networks
- Backhaul, Small cells, Indoor, HetNet



Network Design Considerations and Deployment Concerns for a Ground Aircraft Communication System

Agenda



- Wireless Communications Characterization
- RF Channel Characterization
 - CelSDRxTM
 - Ray Tracing



Wireless Communications Characterization



Wireless Communications Characterization

- We would like present a methodology we used for the NextGen Data Communication System operating at approximately 136MHz
- The same methodology can be applied for AeroMACS at 5.1 GHz
- NASA has engaged CelPlan Technologies to:
 - Collect field data
 - Analyze the propagation characteristics of that part of the spectrum
 - Provide calibrate propagation tables to be used in the CelPlanner Suite software
- A drive test campaign for two airports
 - Chicago (ORD)- busiest airport in the USA
 - Detroit (DTW)
- FAA supported the measurement efforts at both airports
- A PET-2000 transmitter was used to generate the CW frequency with approximately 5W output power
- A B1322N antenna was used (omni 2.4 dBi)



Test vehicle

- Two test vehicles were used
 - One simulated the transmitter
 - Another simulated a moving receiver





Chicago Airport (ORD)

ORD Airport



- Airport and surroundings were modeled in 3 D
- Horizontal resolution of 1 m
- Vertical resolution of 0.5 m



ORD Transmitter Characteristics

Characteristics	TX1	TX2	ТХЗ	
Antenna Type	Omni	Omni	Omni	
Rad Center [m]	7.6	7.6	7.6	
Antenna structure	mast	mast	mast	
Antenna Model	B1322N	B1322N	B1322N	
Azimuth [°]	N/A	N/A	N/A	
Tilt [°]	0	0	0	
Antenna Gain [dBd]	0.26	0.26	0.26	
Latitude [dec deg]	41.97705	41.98861667	41.97447222	
Longitude [dec deg]	-87.9255	-87.89038333	-87.90714722	
Datum	WGS84	WGS84	WGS84	
Obstruction	No	No	No	
Obstruction Azimuth [°]				
Transmitter model	PET-2000	PET-2000	PET-2000	
Transmit Frequency [MHz]	136.475	136.475	136.475	
Signal Bandwidth [KHz]	tone	tone	tone	
Warm-up duration [min]	> 15	> 15	> 15	
ERP [W]	3.95	3.95	3.95	
Weather	Sunny	Sunny	Sunny	

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Wireless Global Technolog



Morphology representation



Topography

Buildings

Morphology

Surroundings Morphology





Drive Test Measurements





9/10/2013

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Measurement x Predictions

• Prediction model used was: Korowajczuk 3D



Calibration Machine														x
Model VI	Log File: C:\Markets\NASA\	ORD\Measu	rements\pr	oc/comb/c	list\. Reco	ds: 221949								
Calibration	Terrain Type Description	Morphology Loss (dB/Km)			Diffraction Factor			Penetration Loss (dB)			Clutter Factor (dB)			Diff.
C Constrained		Value	Fixed	Conv.%	Value	Fixed	Conv.%	Value	Fixed	Conv.%	Value	Fixed	Conv. %	
Unconstrained	0 Open water	1.3000			0.0000			0.0000			0.0000			
Fixed Params	1 Perennial Ice/Snow	1.3000			0.0000			0.0000			0.0000			
Zero Morph. Loss	2 Emergent Herbaceous Wetl	1.3000			0.0000			0.0000			0.0000			Г
	3 Barren Land, Unconsolidat	2.0000			0.0000			0.0000			0.0000			Г
Max. Itt. 100	4 Dwarf Scrub, Grassland/He	2.0000			0.0000			0.0000			0.0000			Γ
Max.big40	5 Scrub/Shrub,Pasture/Hay	2.0000			0.0000			0.0000			0.0000			Г
Mirc sig. (115	6 Cultivated Crops	2.0000			0.0000			0.0000			0.0000			Г
Calibrate Deviation	7 Woody Wetlands	0.0000			0.0000			3.0000			0.0000			7
Chart) from	8 Deciduous Forest	5.0018			0.5196			3.0000			12.4915			~
Manurament	9 Mixed Forest	5.0018			0.5196			3.0000			12.4915			v
Medsurement	10 Evergreen Forest	5.0018			0.5196			3.0000			12.4915			~
Distance	11 Roads	2.3003			0.0000			0.0000			0.0000			Ē
1	12 Streets	1.9424			0.0000			0.0000			0.0000			F
Update Files	13 Airport Runways	3.2668			0.0000			0.0000			0.0000			Ē
Dur Coulder	14 Developed, Open Space	0.3324			0.0000			0.0000			0.0000			Ê
Paste Copy Ligar	15 Developed, Low Intensity	4.0000			0.8665			5.0000			-17.8537			7
Paste to Fixed	16 Developed, Medium Intens	4.4013			0.8665			5.0000			-11.1112			v
Conviron MEL	17 Developed, High Intensit	10.4630			0.0594			5.0000			-3.5565			7
	18 Airport Terminal Fingers	15.0000			0.0000			0.0000			0.0000			Ē
I Info	19 Railways	2.0000			0.0000			0.0000			0.0000			Ê
	20	0.0000			0.0000			0.0000			0.0000			Ē
	21	0.0000			0.0000			0.0000			0.0000			Ê
	22	0.0000			0.0000			0.0000			0.0000			Ē
	23	0.0000			0.0000			0.0000			0.0000			Ē
	24	0.0000			0.0000			0.0000			0.0000			Ê
	25	0.0000			0.0000			0.0000			0.0000			Ē
	26	0.0000			0.0000			0.0000			0.0000			Ê
	27	0.0000			0.0000			0.0000			0.0000			Ē
	28	0.0000			0.0000			0.0000			0.0000			Ê.
	29	0.0000			0.0000			0.0000			0.0000			Ē
	30	0.0000			0.0000			0.0000			0.0000			Ē.
	31	0.0000			0.0000			0.0000			0.0000			Ê
	Nd Type not defined	0.0000			0.0000			0.0000			0.0000			Γ
	Parameter Name	Value	Fixed	Conv. %										
Charles I and a star Dist	Prop. Loss Slope 1 (db/Dec)	33.5028												
Siope Breakpoint Dist.	1 Prop. Loss Slope 2 (db/Dec)	25.0060												
D1: 1000.00 m	2 Prop. Loss Slope 3 (db/Dec)	31.8999												
D2: 3000.00 m														



	Unconstrained Calibration Set								
	Standard Deviation [dB]	Average Deviation [dB]	RMS [dB]						
Model II - 2D Korowajczuk	6.16	0.04	6.16						
Model III - Microcell	6.96	0	6.96						
Model VI - 3D Korowajczuk	6.07	0	6.07						



Predictions x Measurements





Airport 3 D Coverage view





Detroit Airport (DTW)

DTW Airport





- Airport and surroundings were modeled in 3 D
- Horizontal resolution of 1 m
- Vertical resolution of 0.5 m



DTW Transmitter Characteristics

Characteristics	TX1	TX2
Antenna Type	Omni	Omni
Rad Center [m]	7.6	7.6
Antenna structure	mast	mast
Antenna Model	B1322N	B1322N
Azimuth [°]	N/A	N/A
Tilt [°]	0	0
Antenna Gain [dBd]	0.26	0.26
Latitude [dec deg]	42.22115833	42.19732222
Longitude [dec deg]	-83.35130833	-83.37918611
Datum	WGS84	WGS84
Obstruction	No	No
Obstruction Azimuth [°]		
Transmitter model	PET-2000	PET-2000
Transmit Frequency [MHz]	136.425	136.425
Signal Bandwidth [KHz]	tone	tone
Warm-up duration [min]	> 15	> 15
EiRP [W]	3.76	3.76
Weather	Sunny	Sunny

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Morphology representation



Topography

Surroundings Morphology

Buildings Morphology



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Drive Test Measurements







Measurement x Predictions



9/10/2013

	Unconstrained Calibration Set							
	Standard Deviation [dB]	Average Deviation [dB]	RMS [dB]					
Model II - 2D Korowajczuk	6.52	0.09	6.52					
Model III - Microcell	6.13	0	6.13					
Model VI - 3D Korowajczuk	6.53	0.06	6.53					

Model VI		Log File: C:\Markets\NASA\	DTW\Measur	ements\pr	roc/comb/s	appi Recor	ds: 134589	ĩ							
albration	Ī	Tarrain Turne Description	Morphology Loss (dB/Km)			Diffraction Factor			Penetration Loss (dB)			Clutte	er Factor (c	1B)	Dif
C Constrained		Tellen rype presemption	Value	Fixed	Conv. %	Value	Fixed	Conv. %	Value	Fixed	Conv. %	Value	Fixed	Conv. %	ŝ
 Unconstrained 	10	Open water	1.3795		0.21	0.0000		0.00	0.0000		0.00	0.0000		0.00	Ť
Fixed Params	1	Perennial Ice/Snow	1.3795		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	t
Zero Morph. Loss	2	Emergent Herbaceous Wetl	1.3795		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
Zero Penetration	3	Barren Land Unconsolidat	2.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
Max. Itr: 100	4	Dwarf Scrub.Grassland/He	2.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	t
Max.Sig: 40	5	Scrub/Shrub.Pasture/Hav	2.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
Min. Sig: 115	6	Cultivated Crops	2.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	t
Calibrate Deviation	7	Woody Wetlands	0.0000		0.00	0.0000		0.00	3.0000		0.00	0.0000		0.00	
	8	Deciduous Forest	6.3994		0.26	0.2483		4.92	3.0000		0.00	0.0000		0.00	
hart View	9	Mixed Forest	6.3994		0.00	0.2483		0.00	3.0000		0.00	0.0000		0.00	
Measurement	10	Evergreen Forest	6.3994		0.00	0.2483		0.00	3.0000		0.00	0.0000		0.00	
Distance	11	Roads	1.2982		0.03	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	12	Streets	2.0000		0.20	0.0000		0.00	0.0000		0.00	0.0000		0.00	
Update Files	13	Airport Runways	1.5463		1.23	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	14	Developed, Open Space	0.4336		17.13	0.0000		0.00	0.0000		0.00	0.0000		0.00	
Zaste Lopy Ligar	15	Developed, Low Intensity	3.0000		0.00	0.3144		0.00	5.0000		0.00	16.0000		0.00	
Paste to Fixed	16	Developed, Medium Intens	10.9958		0.50	0.3144		52.63	5.0000		0.00	19.0966		0.00	
Constition MEL	17	Developed, High Intensit	15.0000		0.00	0.3144		0.00	5.0000		0.00	22.0000		0.00	
Copy non merc	18	Airport Terminal Fingers	14.3069		0.04	0.0000		0.00	0.0000		0.00	0.0000		0.00	
Info	19	Railways	2.0000		0.02	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	20	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	21	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	22	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	23	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	24	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	25	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	26	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	27	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	28	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	29	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	30	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	31	1	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
	Nd	Type not defined	0.0000		0.00	0.0000		0.00	0.0000		0.00	0.0000		0.00	
		Parameter Name	Value	Fixed	Conv. %										
ol p i 11011	0.	Prop. Loss Slope 1 (db/Dec)	32.0146		19.48										
Slope Breakpoint Dist.	1	Prop. Loss Slope 2 (db/Dec)	26.3380		3.10										
01:[1000.00 m	2	Prop. Loss Slope 3 (db/Dec)	25.0375		0.26										



Measurement x Predictions





Airport 3 D Coverage view





Ray Tracing Predictions



Ray Tracing Prediction

- Ray Tracing requires extremely precise data bases to provide similar results as empirical models
- Processing time is very high when compared to empirical models
- Ray Tracing has a unique property of providing multipath delay predictions





RF Channel Characterization

Multipath Analysis



Multipath fading

- Multipath is a major impairment in wireless communications and should be properly characterized
- Characterization can be done using:
 - Channel response per OFDM sub-carrier
 - Ray Tracing







Channel Response

CelSDRx™



- Universal Software Defined Receiver (SDRx)
- Captures up to 100 MHz of spectrum from 100 MHz to 18 GHz
- Digitizes signal at 125 Msps and provides I and Q components
- Digitally extracts information for any digital technology: LTE, WiMAX, HSPA, UMTS, GSM
- Performs
 - Symbol synchronization
 - Frame Synchronization
 - Sub-Channel Equalization
 - Bandwidth and frame number determination
- Detects
 - RF Channel Response in time and frequency
 - Displays fading amplitude, band and duration
 - Channel Traffic load
 - Received signal coherence from different antennas
 - Received signal coherence to different antennas
- GPS data geo-referencing, allowing drive tests
- Ideal to plan network parameters
- Ideal to scan competitive networks
- Patents applied





CelSDRx [™] Specifications

- Frequency coverage: 100 MHz to 18 GHz
- Instantaneous Bandwidth: 100 MHz
- Displayed Average Noise Level:
 - -115 dBm @ 10 MHz
 - -110 dBm @ 1500 MHz
 - -110 dBm @ 2500 MHz
- Maximum RF input: +10 dBm
- Non-input related spurs: < -100 dBm
- Maximum RF gain: 20 dB
- IF gain: -10 to +30 dB in 1 dB steps
- Power Supply +12 VDC



Impulse Response



Measured Power per Resource Element (dBm)



Frame - Measured Subcarrier Power [dBm]





RF Channel Response (time zoom)



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RF Channel Response (3D detail)



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Adjusted Power per Resource Element (dBm)

Compensated Subcarrier Power [dBm] -10 20 -20 40 -30 60 -40 Symbol -50 80 -60 100 -70 120 -80 -90 140 50 150 200 250 350 450 500 550 600 100 300 400 Subcarrier index

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Traffic view

• Traffic allocation can be visualized per frame



Correlation



- Correlation is considered as the sympathetic movement of two or more variables
- Pearson's Product-Moment Correlation Coefficient

$$r_{xy} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}},$$

- The correlation coefficient varies between +1 and -1
 - Positive Correlation: movement is in the same direction
 - Negative Correlation: movement is in the opposite direction
- Reference signals transmitted by two antennas can be used to establish the channel response
- The correlation coefficient for the two channel responses can then be calculated



Correlation between antennas

 Correlation index between two antennas CI=0.42





Antenna Correlation Drive

Antenna correlation variation







Multipath using Ray Tracing



Multipath between moving airplanes





Conclusions

- Propagation characteristics were calculated for two airports
- Parameter reusability showed a good agreement for similar size airports
- Parameters will vary for smaller airports, with less obstructions
- Shadows and interference can be calculated for different transmitter locations
- The propagation parameters were then applied to the CelPlanner prediction software
- A special interface (API) was developed that allows the CelPlanner SW to provide data to other simulation tools
- The same methodology can be applied to other bands, like AeroMACS (5091 to 5150 MHz)
- Ray tracing can be used to perform predictions
- CelPlan can uniquely characterize multipath through
 - Channel Response determination
 - Ray tracing
- CelPlan can be your partner for a reliable design of AeroMACS





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Questions?