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## Minds in Motion

## Techniques for Analyzing, Testing, **Commissioning and Managing ZigBee Networks**

**Jason Choong** Daintree Networks, Inc.



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## Overview

- Presentation describes requirements and challenges for testing, analyzing, commissioning and managing
- Covers key aspects of the design and deployment lifecycles



- In the field, by installers & end-users
- Describe challenges, solutions and experiences with testing and analysis of ZigBee networks Minds in Motion

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**Development Testing** 

### **Protocol Analysis**

## **Development Testing with Protocol Analysis**

- Main requirement here is verifying that:
  - The application was correctly implemented.
  - Protocol transactions are correct.
- Main tool used here is a protocol analyzer to "sniff" packets.
  - Commonly used tool.
  - Focus instead on what's different about ZigBee for protocol analysis.

Packet List

S./. Time

	Packet Data	
Packet Decode Frame 22 (Length = 33 bytes) IEEE 802.15.4 ZigBee NUK ZigBee APS	00000:       61       88       23       11       03       01         0006:       00       00       00       44       00       01         000c:       00       00       00       70       250         0012:       0a       00       04       01       0a       21         0018:       00       05       00       00       01       00         001e:       00	a.# 
Frame Control: 0x50     Destination Endpoint: 0x0a     Cluster Identifier: General:     Profile Identifier: Home Aut     Source Endpoint: 0x0a     ZigBee AF     AF Header: 0x21	Basic (0x00) tomation (0x0104)	
Transaction 1 Transaction Sequence Numb JigBee MSG JigBee ZCL	per = 0x00	
<ul> <li>FrameControl: 0</li> <li>FrameType: 00 (0</li> <li>VendorSpecific: 0</li> <li>GroupIdentifierPr</li> <li>Reserved: 0000 f</li> <li>CommandIdentifier: 1</li> </ul>	Command acts across the entire prof: ) (The manufacturer code field sha: cesent: 0 (The group identifier fie (Reserved) 0 (Read attribute)	ile) Ll not be eld shall
⊢ FramePayload: 01:00:00 ⊢ ReadAttributeFrame AttributeDataType AttributeIdentifi	e: 1 (Unsigned 8-bit integer) Ler: 0 (HWRevision)	
est FD ADS Drofile ADS Cluster Dr	otocol Backet Tume	
ZDP End Device B Ziç	pbee MSG ZDP:End Device Bind Req	

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18	02:23:49.542	0x0001	0x0000	0x00	0x00	ZDP	End Device B	Zigbee MSG	ZDP:End Device Bi	ind Req	
19	02:23:49.543							IEEE 802	Acknowledgment		
20	02:23:49.553	0x0000	0x0001	0x00	0x00	ZDP	End Device B	Zigbee MSG	ZDP:End Device Bi	ind Rsp	
21	02:23:49.554	photos an an	10-point all succession	10-2-03-00	100 C 100 S 20	2004.00	A MERCHANNEL AND	IEEE 802	Acknowledgment		
22	02:23:56.481	0x0000	0x0001	0x0a	0x0a	HA	General:Basic	Zigbee MSG	HA:General:Basic		
23	02:23:56.482							IEEE 802	Acknowledgment		
24	02:23:56.487	0x0001	0x0000	0x0a	0x0a	HA	General:Basic	Zigbee APS	APS Ack		
25	02:23:56.489							IEEE 802	Acknowledgment		
26	02:23:56.490	0x0001	0x0000	0x0a	0x0a	HA	General:Basic	Zigbee MSG	HA:General:Basic		
27	02:23:56.491							IEEE 802	Acknowledgment		
28	02:23:56.497	0x0000	0x0001	0x0a	0x0a	HA	General:Basic	Zigbee APS	APS Ack		-
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NWK Src NWK Dest APS Src EP APS

### Development Testing with Protocol Analysis Finding Packets of Interest

🚟 Visual Device Layout

0004

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0001

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0003

- ZigBee networks have:
  - Many devices.
  - Multi-hop meshed networking.
- Finding packets of interest can be a challenge. In any time interval:
  - Many devices could be transmitting.
  - A single packet could be transmitted multiple times on a multi-hop route.

Packe	et List						
Se /	Time	MAC Src	MAC Dest	NWK Src	NWK Dest	Packet Type	
531	14:25:26.396	0x287c	Oxffff	0x0004	Oxffff	NWK Command: Route Request	
532	14:25:26.462	0x287c	Oxffff	0x0004	Oxffff	NWK Command: Route Request	
533	14:25:26.529	0x0000	Oxffff	0x0004	Oxffff	NUK Command: Route Request	
534	14:25:26.828	0x21b3	Oxffff	0x0004	Oxffff	NWK Command: Route Request	
535	14:25:27.016	0x21b3	Oxffff	0x0004	Oxffff	NWK Command: Route Request	
536	14:25:27.182	0x21b3	Oxffff	0x0004	Oxffff	NWK Command: Route Request	4704
537	14:25:27.224	0x0004	0x0003	0x0004	0x287d	ZTP:Transmit counted packets	1/90
538	14:25:27.226	0.0 00015-000		and the second second	State of the second	Acknowledgment	7
539	14:25:27.229	0x143e	0x0002	0x143e	0x0002	NUK Command: Route Reply	
540	14:25:27.229	0x0003	0x0002	0x0004	0x287d	ZTP:Transmit counted packets	
541	14:25:27.231					Acknowledgment	
542	14:25:27.235	0x0002	0x143e	0x0004	0x287d	ZTP:Transmit counted packets	
543	14:25:27.236					Acknowledgment	
544	14:25:27.239	0x143e	0x287d	0x0004	0x287d	ZTP:Transmit counted packets	
545	14:25:27.244					Acknowledgment	
546	14:25:27.246	0x143e	0x287d	0x0004	0x287d	ZTP:Transmit counted packets	
547	14:25:27.304	0x259e	Oxffff	0x0003	Oxffff	NWK Command: Route Request	
548	14:25:27.334	0x0003	Oxffff	0x0003	Oxffff	NWK Command: Route Request —	~~~
🔶 End F	'irst Stream					-	
•							



287d

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0002

## Development Testing with Protocol Analysis ZigBee Cluster Library and Verifying New Application Profiles

- You will be developing or extending your application profile.
  - Some may be based purely on public profiles and specifications.
  - Some may be proprietary, and some may be private.
- New ZigBee Cluster Library (ZCL) will speed up your development by

allowing you to select clusters from libraries and re-use them for your own applications.

Library	Available Clusters
Name	Name
General Liebting	Basic Power configuration
Measurement	Device Temperature Configuration
HVAC	Identify
Closures	Groups
Security and	Scenes
Protocols	On/Off
	On/Off Switch Configuration
	Level Control
	Alarm Notification
	Alarm Configuration
	Events
	Time

Id       Name         0x0000       General:Basic         0x0001       General:Identify         0x0002       General:Identify         0x0003       General:Identify         0x0004       General:On/Off         0x0005       General:Con/Off         0x0006       General:Con/Off         0x0007       General:Con/Off         0x0008       General:Con/Off         0x0009       General:Con/Off         0x0010       Measurement and Sensing:Illuminance measurement notification         0x0020       Measurement and Sensing:Temperature measurement configuration         0x0025       Measurement and Sensing:Temperature level sensing configuration         0x0026       Measurement and Sensing:Pressure measurement configuration         0x0027       Measurement and Sensing:Pressure measurement configuration         0x0028       Measurement and Sensing:Pressure measurement configuration         0x0029       Measurement	Id: 0x01	04 Name: Home Automation Abbrev: HA
Id         Name           0x0000         General:Basic           0x0003         General:Identify           0x0004         General:On/Off           0x0005         General:On/Off           0x0006         General:Level Control           0x0007         General:Scenes           0x0020         Measurement and Sensing:Illuminance measurement notification           0x0021         Measurement and Sensing:Illuminance level notification           0x0022         Measurement and Sensing:Illuminance level sensing configuration           0x0023         Measurement and Sensing:Temperature measurement notification           0x0024         Measurement and Sensing:Temperature level sensing configuration           0x0025         Measurement and Sensing:Temperature level notification           0x0026         Measurement and Sensing:Temperature level sensing configuration           0x0027         Measurement and Sensing:Temperature level sensing configuration           0x0026         Measurement and Sensing:Pressure measurement configuration           0x0029         Measurement and Sensing:Pressure measurement configuration           0x0020         Measurement and Sensing:Plow measurement configuration           0x0027         Measurement and Sensing:Cocupancy sensing configuration           0x0028         Measurement and Sensing:Cocupancy sensing c	Description	n: Home Automation Profile based on ZigBee Cluster Library
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0x00a3 Security and Safety:IAS WD	0x00a3	Security and Safety:IAS WD



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## Development Testing with Protocol Analysis ZigBee Cluster Library and Verifying New Application Profiles

Simple example from a test event

- "Identify" cluster is a new ZCL cluster that facilitates the identification of devices (e.g., to select a subset of devices for specific action).
- In the test event, a proposal was made to add additional commands to this cluster command IDs 0x02 and 0x03.





System Verification

### **Network Analysis**

## System Verification with Network Analysis

- Situation
  - Application has been developed.
  - Verified for a small handful of devices.
- Next step
  - Test a larger system more closely matching likely usage in your commercial solution.
    - More end devices.
    - Add routers to achieve multi-hop networking.
    - Devices distributed over larger area.



## System Verification with Network Analysis Distributed Analysis



**Capture Node** 

Ethernet or Wi-Fi Connection

**End Device or Router** 

- System will be:
  - Spread over a larger area.
  - Probably across different rooms, buildings or areas.
- Capturing packets
  - Single node will not pick up all the packets.
  - Multiple capture nodes will be required.
  - Key requirements for distributed analysis:
    - Multiple capture nodes.
    - Clocks synchronized.
    - Capture nodes must be networked (e.g., via Ethernet or Wi-Fi).
- The result:
  - Single view of all packet exchanges for the entire network.

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## System Verification with Network Analysis Analyzing Network Formation

- Analysis of network formation involves validating the following:
  - Did the device join the network?
  - How and where did the device join the network?
  - Is the network structure acceptable?
- The example below shows a tree being detected as devices join the network. A device joins the network by associating with a device already on the network.



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## System Verification with Network Analysis Analyzing Mesh Connectivity

- ZigBee offers mesh networking.
  - Multi-hop connectivity
  - Devices separated by larger distances
  - Resiliency from temporary radio fading and interference
- Only effective if there are redundant paths through the network.
- The link quality indicator (LQI) is an indicator of this effectiveness.
  - Ensure sufficient redundant paths through the network for all devices.
  - Sections of the network should not be isolated (in an RF sense) from each other.



## System Verification with Network Analysis Tracing Packet Flows

- When packets do not reach their intended destination, it may be necessary to trace packet flows.
  - Which route did the packet take? Which routes failed? Why?
- This example shows a visual representation of such a trace.



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### System Verification with Network Analysis Tracing Packet Flows

5 Time	Src	Dest	MAC Seq No	NWK Src	NWK Dest	Packet T	Уре		Cross-refere	nce to
End Formation	0.0.45	0.07.0	0.07	0.0.45		-	10 11		01033 101010	
326 14:59:28.771607	0x0a47	0x07e9	UX87	0x0a47	0x0000	Reserved	(Secured)		nrotocol ana	lyzar ta
.327 14:59:28.782707.	. UXU847	0x07e9	UX8/	0x0a47	0x0000	Reserved	(Secured)		protocol and	IYZEI IU
.320 14:39:20.707313.	. 0x0a47	0x07e9	0.07	0x0a47	0x0000	Reserved	(Secured)		abtain noolu	at light to
-329 14:39:20.790013. 346 14:59:20.90013.	0x0a47	0x0789	0x07	0x0a47	0x0000	Reserved	(Secured)		Optain packe	
247 14:39:20.003392.	. 0x0a47	0x0970	0x00	0x0a47	0x0000	Reserved	(Secured)		e eza e	
400 15:02:25 952701	. 0x09/4	0x0000	0x30	0x0a47	0x0000	Reserved	(Secured)		did a little de	eper
400 13:03:23.032/01.	. 0x0a4/	0x0970	0x09	0x0a47	0x0000	Reserved	(Secured)		ang a male at	00000
A02 15:03:25.050907.	0x0974	0x0000	0x30	0x0a47	0x0000	Reserved	(Secured)			
403 15.03.25.910313.	· 0x0a47	0v0074	0x3e	0x0a47	0×0000	Reserved	(Secured)			
Fud First Streem	. 0.0447	0x0974	UNUA	0X0447	00000	RESELVED	(Secured)	10000		
LIIG TILSC SCIEda										
						1	90	<b>–</b>		
(					O4be	94.4	<u>,</u>		0000	00
Filter	NWK 🕨	Source	e and Destination	n Device	D <sup>04be</sup>				0000	
Filter	N₩K ► 07e9	Source	e and Destination	n Device	<b>D</b> <sup>04be</sup>			97d	0000 07e9	
Filter	N₩K ► 07e9	Source	e and Destination	n Device	O4be	1718		97d	)0000 (07e9	00
	N₩K ) 07e9	Source	e and Destination	n Device	<b>0</b> 4be	171e		97d	) <sup>0000</sup>	00
Filter	N₩K ) 07e9	Source	e and Destination	n Device	<b>D</b> <sup>04be</sup>	171e		97d	<b>0000</b> <b>07e9</b>	00
<ul> <li>Filter</li> <li>View Size</li> <li>Print Preview</li> <li>Print Setup</li> <li>Print</li> </ul>	N₩K ) 07e9	Source	e and Destination	n Device	<b>P</b> <sup>04be</sup>	171e		97d	<b>0000</b> <b>07e9</b>	00
Filter       Filter       View Size       Print Preview       Print Setup       Print       Background Image	N₩K ) 07e9	Source	e and Destinatio	n Device		171e	•	97d	0000 07e9	000
	N₩K ► 07e9	Source	e and Destinatio	n Device	O4be	171e		97d	0000 07e9	
	NWK ♪ 07e9	Source	e and Destinatio	n Device	O4be	171e		97d	0000 07e9	

## System Verification with Network Analysis Tracing Application Layer Messages

- Analysis of application layer messages encompasses:
  - What are the messages being sent between endpoints?
  - Are the right messages and values being sent?
- Example below shows active endpoints (red rectangles) for each device (blue circles).



## System Verification with Network Analysis Tracing Application Layer Messages

To analyze and troubleshoot further, cross-reference back to protocol analysis.



**TEXAS INSTRUMENTS** 



System Verification

### **Performance Analysis**

## System Verification with Performance Analysis

- Situation
  - Functional aspects examined.
- Next step
  - Validate that the system meets the application requirements.
  - Works correctly as part of the large system.

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### System Verification with Performance Analysis Scenarios

- A "light" network of:
  - 20 sensors.
  - Collecting readings every five minutes.
  - Occasional data loss is acceptable.
- Less susceptible to performance issues.

- A "heavier" network of:
  - 300 sensors and actuators.
  - Sensors generate updates every five seconds.
  - Commands to actuators cannot be lost, but delays are acceptable.
  - Loss is unacceptable.
- This network is likely to be heavily loaded and could suffer from congestion. Furthermore, packet losses must be minimized, but some delay is acceptable.

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### System Verification with Performance Analysis Performance Metrics

- Key metrics
  - End-to-end packet count/loss
  - End-to-end data rate/throughput
  - End-to-end delay
  - These describe the overall network performance.

- Other metrics
  - Per-hop data rate/throughput
  - Per-hop delay
  - Individual device (router) loading

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## System Verification with Performance Analysis Network Design Considerations

- Goal of performance analysis
  - Specify network designs to meet the application's performance requirements.
- Some basic guidelines are:
  - Avoid congestion & bottlenecks.
    - Physical layout or the use of star networks.
    - Reduce delay and packet losses.
  - Maximize redundant paths (meshed networking).
    - Alternative routes during short-term radio fading or interference.
    - Multiple routers are within (reliable) radio range.
- Create rules for network design and layout for installers to follow.
  - Don't place near certain objects, for every X end device, have Y routers, etc.



System Verification with Performance Analysis Obtaining Performance Measurements

- Measurements can be obtained by observing the packet exchanges between devices
- Visual measurements can quickly highlight issues.



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## System Verification with Performance Analysis Obtaining Performance Measurements

Numerical measurements can provide network-wide performance summaries.

Measurements								
Measurement Name	MAC Tx ReTx Cum. (packets)	MAC Tx Cum. (packets)	NWK Tx Cum. (packets)	NWK Tx Cum. (max bps)	NWK Routed Cum. (max bps)	NWK Avg Latency Cum. (ms)	NWK Max Latency Cum. (ms)	NWK Lost Packet Cum. (packets)
😑 Channel Summary	34	1584	318	6336.00	3472.00	7.67	50.79	4
🖃 PAN ID: 1234	34	1417	318	6336.00	3472.00	7.67	50.79	4
🛨 Device: 0000 (a20000000000000)	10	120	15	576.00	448.00	50.79	50.79	0
Device: 0001 (1111111111133)	0	52	1	112.00	0.00	-	-	0
🗄 Device: 071e (a10000000000000)	3	44	1	128.00	576.00	=	-	0
🛨 Device: 0e3b (11111111111122)	0	13	0	0.00	0.00		-	
🗄 Device: 0e3c (3a0800000000000)	0	192	0	0.00	560.00	-	-	0
🗄 Device: 0002 (2a0800000000000)	4	221	0	0.00	560.00	-	-	0
🗄 Device: 071f (4a0800000000000)	0	182	0	0.00	560.00	-	-	0
	1	195	1	128.00	1152.00		-	1
E Device: 0720 (170000000000000)	0	148	0	0.00	448.00	-	-	0
∃ Device: Obdb (a00000000000000)	- 1	37	0	0.00	0.00	r	-	0
	2	17	0	0.00	0.00	/-	-	2
	0	34	0	0.00	448.00	/ -	-	0
🖃 Device: 04bf (9f0000000000000) 🖊	6	50	14	576.00	560.00	ø.00	0.00	0
Route-Thru	0	15	15	560.00	560.00	- 1		
🖃 NUK Streams Summary	-	6	6	576.00	80	0.00	0.00	2
<b>: :: ::::::::::::::::::::::::::::::::</b>		2	2	128.00	-	-	-	0
+ Stream: 0000	-	1	1	576.00	62	0.00	0.00	0
+ Stream: Oe3b	_	2	2	576.00	÷	-	-	2
+ Stream: Oe3d	-	1	1	576.00	80	0.00	0.00	0
Device: 097e (IIIIIIIIIIIIIII)	0	15	0	0.00	448.00	-	-	0
	0	17	0	0.00	352.00	-	-	1
	4	15	6	1264.00	112.00	6.09	6.27	0
Device: 0e3d (all11344e5f6abcd)	0	7	2	688.00	112.00	0.00	0.00	0
⊞ Device: 0196 (a444123412841234)	0	2	0	0.00	112.00		-	0
All devices 04bf sent packets to (and the associated performance)	s struggling to y neighbors w gh retransmis	be /ill sions	End- route	to-end late	ncy for all	Pac	ket loss indic	ator
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Commissioning & Management

#### Design, Configuration, Verification, Management

## **Commissioning & Management**

- Situation
  - The system has been verified.
- Next steps
  - Setting up the end-user or professional installer for success.
  - Key objective is to ensure that the task of commissioning and managing a ZigBee system is relatively straightforward and easy, with appropriate tools.

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### Commissioning & Management Key Considerations

- Application developers should consider network deployment and management requirements.
  - How will the system be commissioned?
  - How will success be determined?
  - What are the requirements for ongoing maintenance and management?
  - What tools are required?

- The solution must reflect specific requirements during installation & management and skills of installers, which are often different from developers or engineers.
- Scope includes:
  - System design and planning.
  - Simple and easy configuration and commissioning of devices.
  - Device and system verification.
  - Ongoing management of the system.

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## Commissioning & Management System Design & Planning

 Prior to actual commissioning, a design/planning phase may take place for larger systems.



- The tasks in this phase include:
  - Dimensioning the system:
    - Quantities of each device type.
    - Cost estimation (especially for tenders).
  - Ensure effective wireless connectivity:
    - With device and router placements.
    - Interference by and to other wireless technologies.

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## Commissioning & Management Simple & Easy Commissioning

- With a plan in place, installers (often electricians) will install devices according to the plan.
- The tasks include:
  - Device placement and configuration, including:
    - Channel selection, network ID and security information.
  - Tracking and logging of device information, including:
    - Matching serial numbers to specific devices.
  - Application bindings, grouping and settings.
    - Binding a light bulb to a switch, setting thermostat levels, etc.
- Much of the complexity of working with wireless infrastructure must be hidden from the installer/end-user.

				-		
: 	Joined	Channel	Ext. Pan ID	Pan ID	Short Addr	
			0.0000		0.0000	_
		11	0x0000	00000	0x0000	
¥ 000000000000000000		11	0x0000	0x0000	0x0000	
✓ 000000000000000000000000000000000000		11	0x0000	0x0000	0x0000	
✓ 000000000000000000000000000000000000		11	0x0000	0x0000	0x0000	
✓ 000000000000000000000000000000000000		11	0x0000	0x0000	0×0000	
¥ 000000000000000000000000000000000000		11	0x0000	0x0000	0x0000	- 1
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## Commissioning & Management Device & System Verification

- Prior to completion:
  - Feedback on installation success and failure.
  - Ongoing monitoring and failure detection may be required for larger, more complex systems.
- The tasks in this phase include:
  - Operational
    - Device is active, device joins network.
  - Configuration
    - Correct binding and group settings.
  - Connectivity
    - Devices can reach each other.
  - Performance
    - Network and router performance meets requirements.
  - Alerts and logs
- Again, simple report/results are required, depending on the skills and knowledge of the installer





## Commissioning & Management Management & Maintenance

- Ongoing management and maintenance is often required to ensure operational efficiency, or to handle addition, replacement or reconfiguration of devices or the system.
- The tasks in this phase include:
  - Upgrade of devices
    - Over-the-air or wired upgrades
  - Device and asset tracking
    - Locationing systems
  - Device management
    - Add/remove/reconfig devices

- Unique and powerful features available on TI's CC24xx product family that can aid in management and maintenance:
  - Over-the-air firmware download to simplify in-the-field upgrades
  - Automatic locationing of devices for applications requiring location information and simplify the installation and management task

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## Conclusion

- In this presentation, we have:
  - Examined requirements, challenges and techniques for testing, analyzing, commissioning and managing wireless sensor systems based on 802.15.4 and ZigBee.
  - Discussed requirements for development, system testing, field trials and deployment.
- For more information
  - Learning: <u>http://www.daintree.net/learning/learning.htm</u>
  - Product: <u>http://www.daintree.net/products/products.htm</u>
  - ZigBee: <u>www.zigbee.org</u>

#### Minds in Motion

March 7-9, 2007 • Dallas, TX

## Techniques for Analyzing, Testing, Commissioning and Managing ZigBee Networks

Jason Choong Director, Marketing Daintree Networks, Inc. jchoong@daintree.net

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Mailing Address: Texas Instruments Post Office Box 655303 Dallas, Texas 75265

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