

MSP430 Advanced Technical Conference 2006



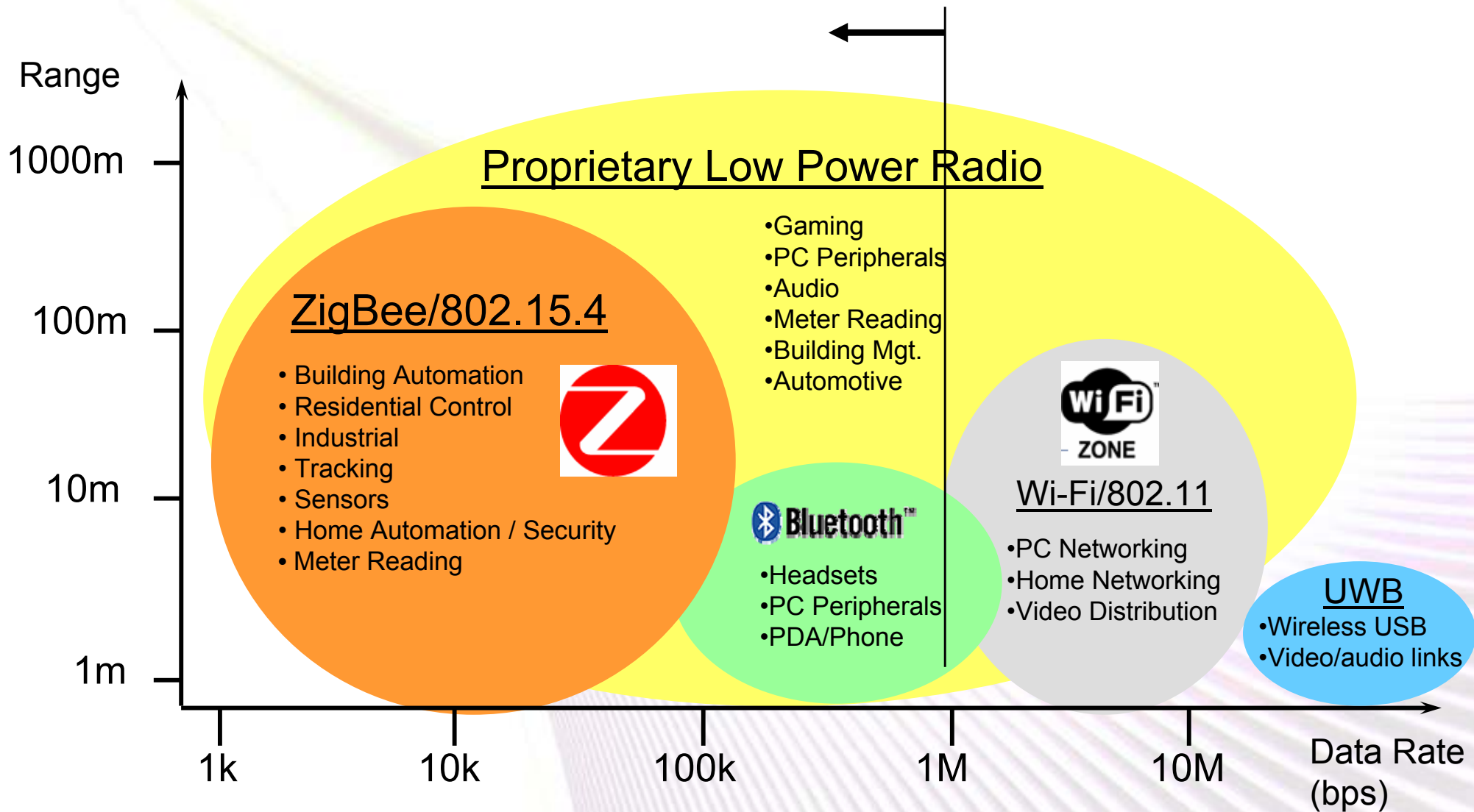
MSP430 Goes Zigbee/802.15.4

Peter Forstner
MSP430 FAE Europe
Texas Instruments

Agenda

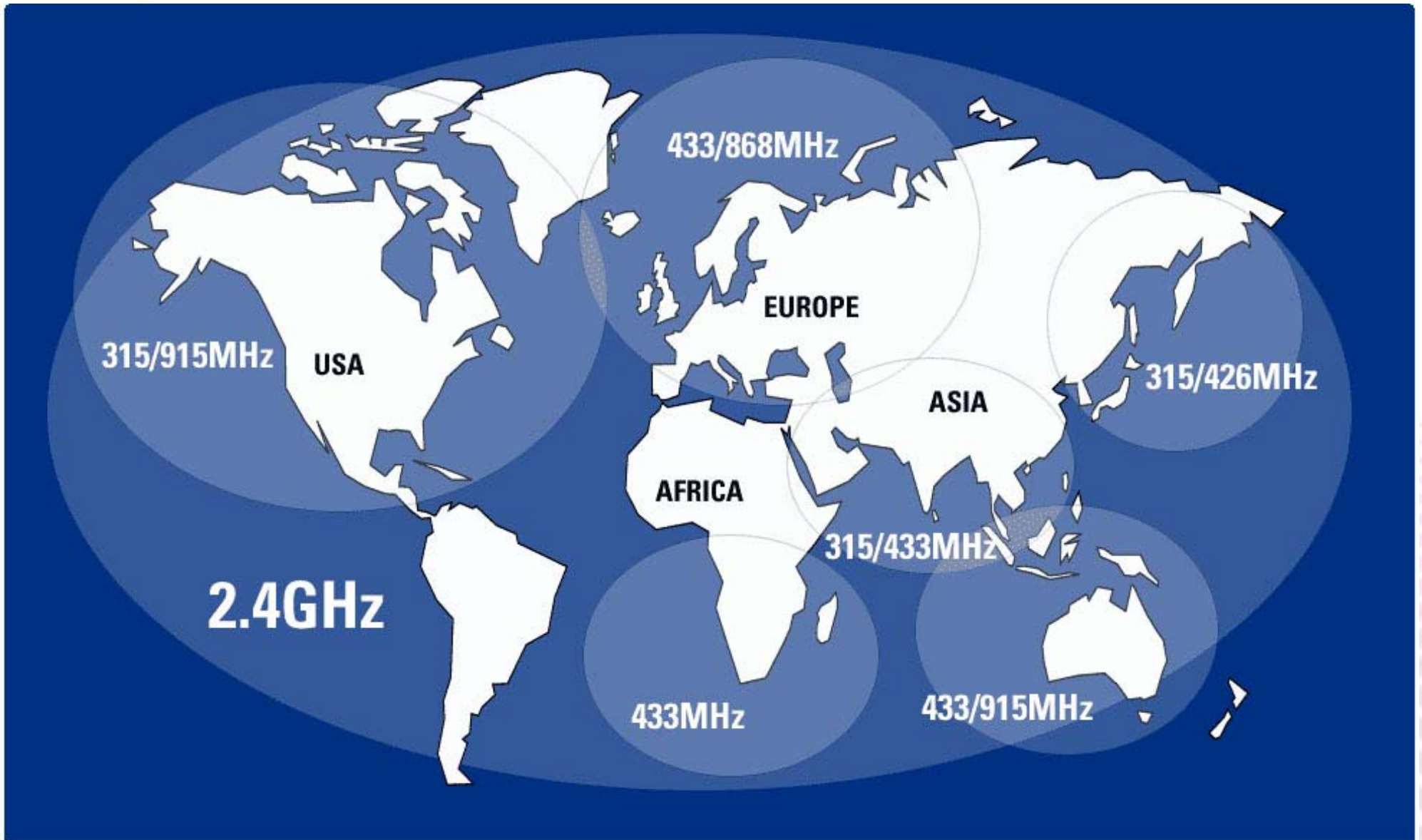
- About 802.15.4 and ZigBee
- Introduction to ZigBee
- MSP430 802.15.4/ZigBee solutions
- Demonstration:
4-node ZigBee network application
- Application Design Considerations
- Facts, statistics & other information

Wireless Solution Spaces



© 2006 Texas Instruments Inc, Slide 3

Frequencies for free

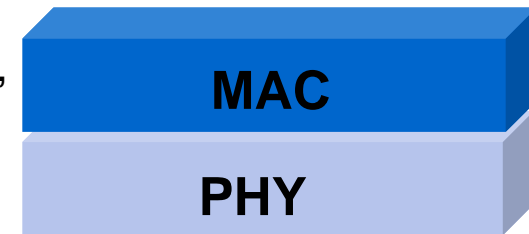


© 2006 Texas Instruments Inc, Slide 4

What is IEEE 802.15.4?

- **IEEE standard for low data rate wireless**
 - First version in October 2003
 - New version since June IEEE 802.15.4-2006 (Rev B) approved, going through final editing before being published shortly
 - New version usually free after 6 months
 - <http://standards.ieee.org/getieee802/>
- **Personal Area Network (PAN)**
- **Defines the Physical (PHY) and Medium Access Control (MAC) communication layers**
- **Focus on low power, low cost and robust**
- **Battery life extension by selectable latency**
- **4 packet frame types:**
 - Data, Acknowledgement, MAC Command, and Beacon.
- **Typical range for IEEE 802.15.4:**
 - Indoor 10 - 30 meters;
 - Outdoor 100 – 150 meters w/o PA; w/ PA 540 meters outdoor

PA = Power Amplifier

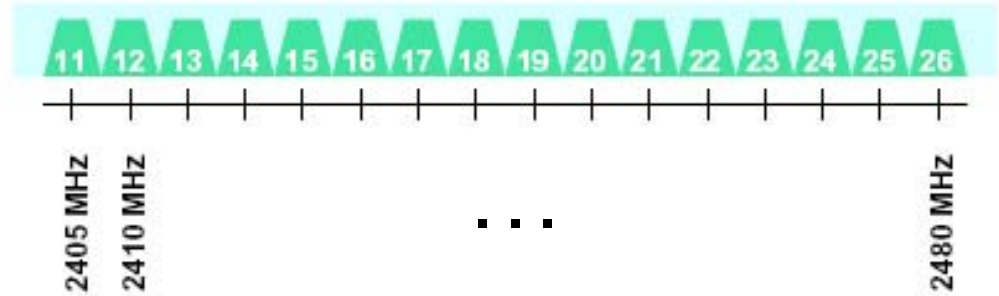
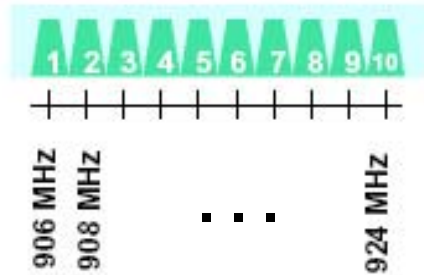


© 2006 Texas Instruments Inc, Slide 5

IEEE 802.15.4 Frequency Allocation

Europe, Asia

 , Pacific



868 MHz
20 kbps
300 kchip/s

915 MHz
40 kbps
600 kchip/s

2.4 GHz
2.5 Mchips/s
O-QPSK
half-sine pulse shaping
-85 dBm

BPSK modulation
RC pulse shaping $\alpha=1$
rx sensitivity -92 dBm

Source: Dr. Heinz Mathis

Frequency	Europe 868 MHz, 1 channel	Americas 915 MHz, 10 channels	Worldwide 2.4 GHz, 16 channels
Data Rate	20kbps ... 100kbps	40kbps ... 250kbps	250kbps

© 2006 Texas Instruments Inc, Slide 6

What is ZigBee?

- **Software Stack on top of IEEE 802.15.4**
- **Standard specifications for LR-WPAN/Sensor and Control wireless mesh networking**
- **Low cost**
- **Low power consumption, Long battery life**
- **Low data rate**
- **No band cost (Unlicensed) - ISM band**
- **Secure data**
- **Standard and custom application profiles**

ZigBee™ – ZigBee Alliance

- “The ZigBee Alliance is an association of companies working together to enable reliable, cost-effective, low-power, wirelessly networked monitoring and control products based on an open global standard”
- Source: ZigBee Alliance homepage
- Through the Chipcon acquisition, TI is now central in the alliance
- Promoters of the ZigBee alliance are: BM Spa, TI/Chipcon, Ember, Freescale, Honeywell, Mitsubishi Electric, Motorola, Philips, Samsung, Schneider Electric, ST, Siemens and Huawei
- The alliance has over 200 members
- For further information please see:
<http://www.zigbee.org/>

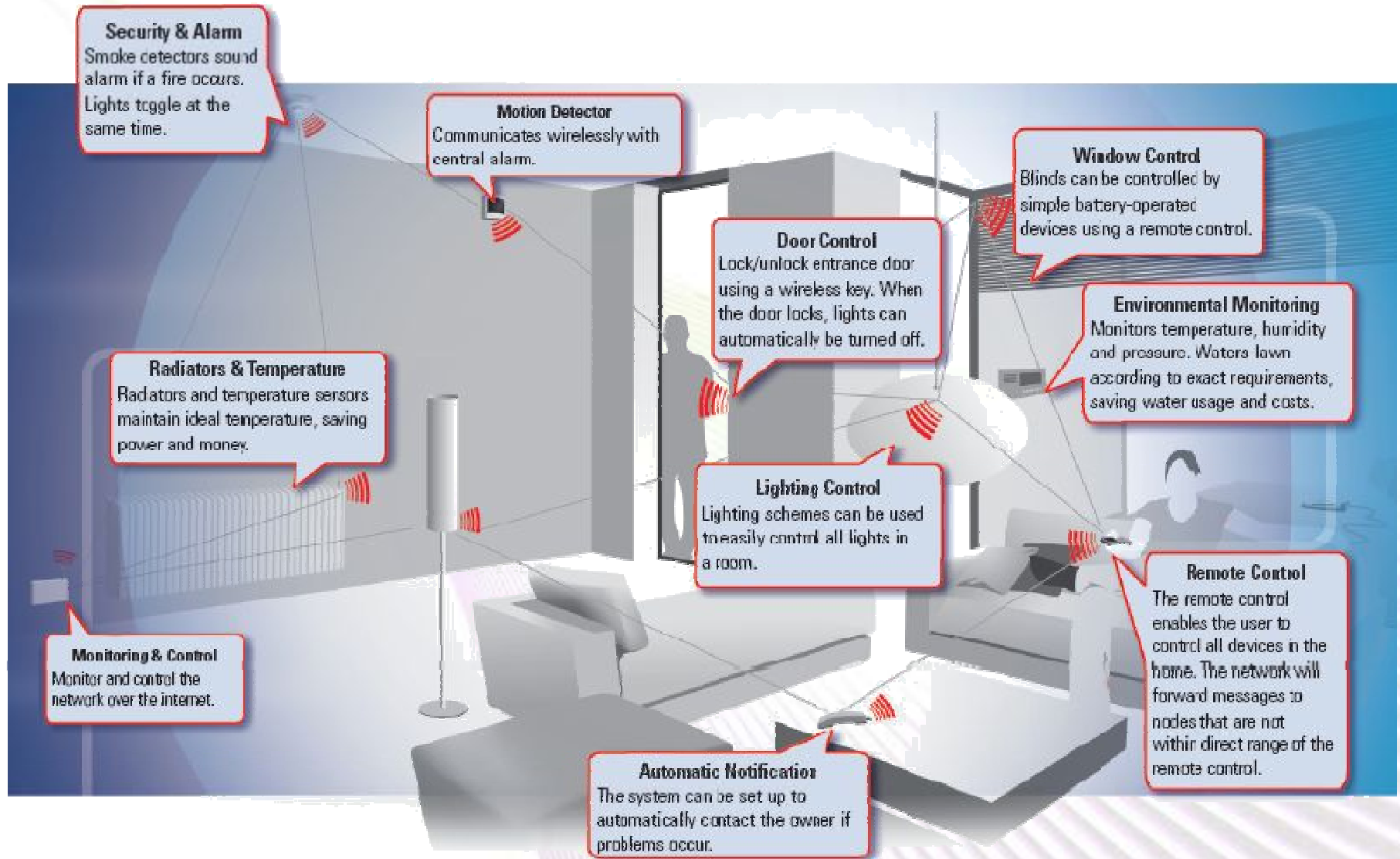


© 2006 Texas Instruments Inc, Slide 9

ZigBee Promoter Companies



ZigBee Example Applications

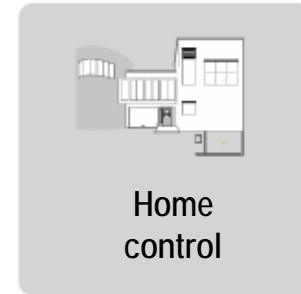


© 2006 Texas Instruments Inc, Slide 11

ZigBee – Main Application Areas

- **Home Automation**

- Automatic Meter Reading (AMR),
- Lighting, Heating, Alarm, Security
- White Goods health status monitoring



- **Commercial Building Automation**

- Heating Ventilation & Air Condition (HVAC)
- Energy management
- Alarm, Security

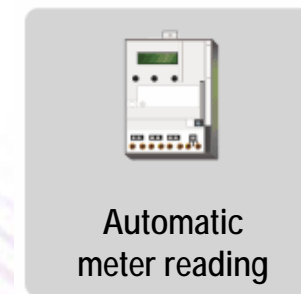


- **Industrial Automation**

- **Hospital and Patient Care**

- **Asset tracking / Active RFID**

- With CC2431 location technology



- **Wireless Sensor Networks**

ZigBee Products – Key Features

- **Very long battery life**
- **Low node cost**
- **Easy to deploy
(low installation cost and simple network commissioning)**
- **Self healing in Mesh networks**
- **Supports large networks**
- **Low data rate
(intended for monitoring & control)**
- **Standardized protocol
(interoperability)**
- **Profiles to enable interoperability of products from different vendors**



Home control



Industrial & commercial



Automatic meter reading

Agenda

- About 802.15.4 and ZigBee
- Introduction to ZigBee
- MSP430 802.15.4/ZigBee solutions
- Demonstration:
4-node ZigBee network application
- Application Design Considerations
- Facts, statistics & other information

ZigBee Feature Set

- **Logical Device Types**
 - Coordinator, Router and End Device
- **Ad-hoc self forming networks**
 - Mesh, Cluster Tree and Star Topologies
(Star Topology for max 14 devices; no stack profiles available for >14 devices)
 - Reliable broadcast messaging
 - Non-guaranteed message delivery
- **Applications**
 - Device and Service Discovery
 - Optional acknowledged service
 - Messaging with optional responses
 - Mechanism to support mix of Public and Private profiles in the same network.
- **Security**
 - Symmetric Key with AES-128
 - Authentication and Encryption at MAC, NWK and Application levels.
 - Key Hierarchy: Master Keys, Network Keys and Link Keys
- **Conformance Certification (Platform and Logo)**

ZigBee Device Types

- **PAN Coordinator**

- One PAN Coordinator per WPAN
- Forms the network by allowing joining all other forms of ZigBee devices

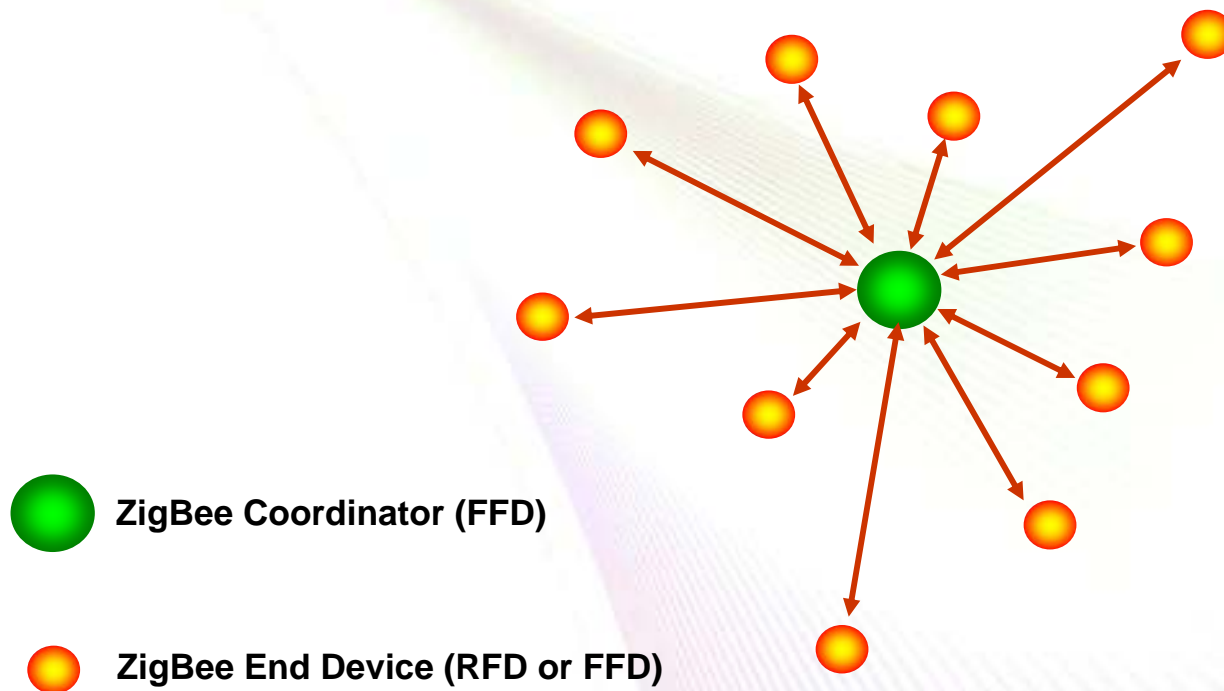
- **Router**

- Scans to find an active channel to join a PAN
- Permits other devices to join
- Routes data

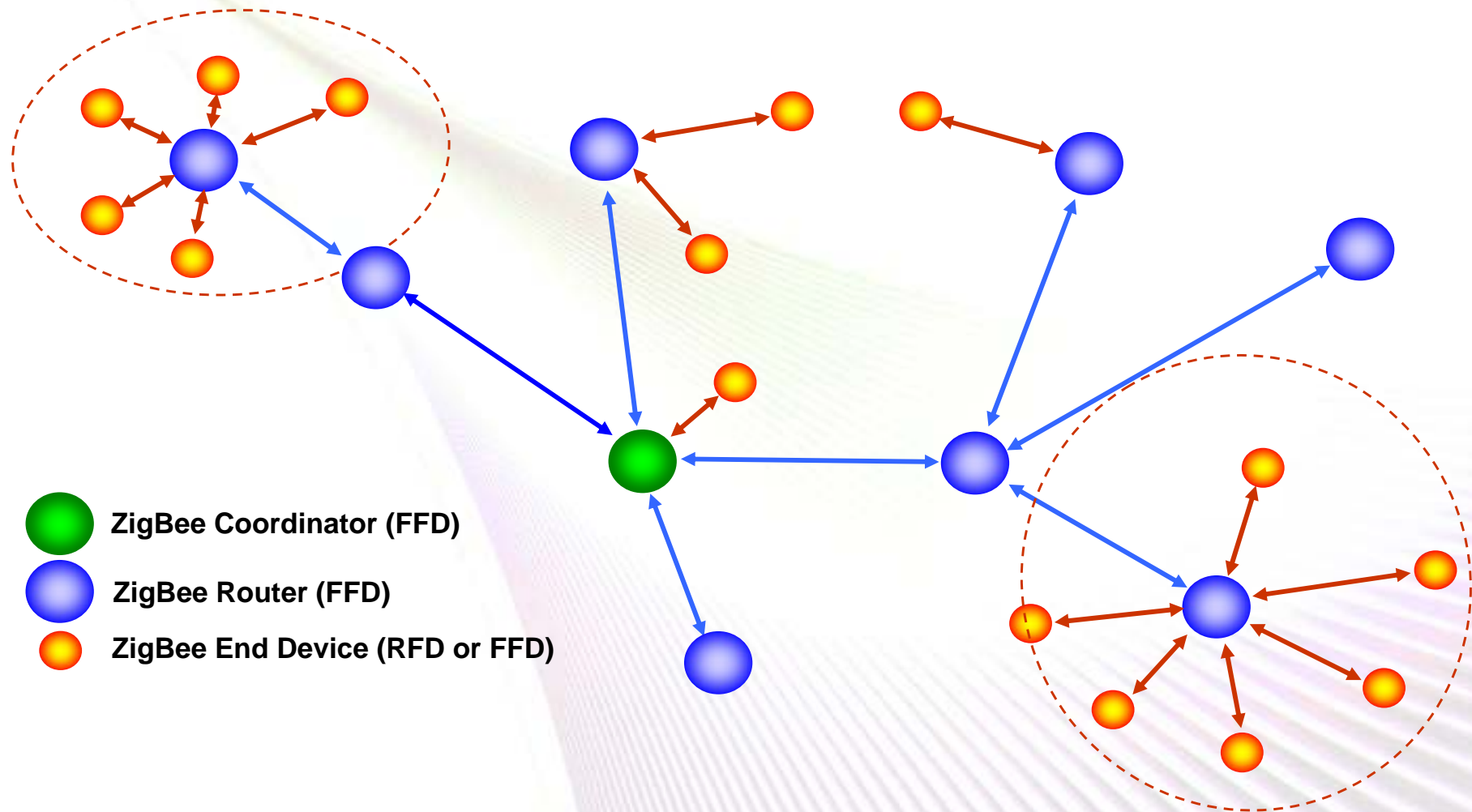
- **End Device**

- Joins either Coordinator or Router
- Sends data to the associated device only
- Incapable of joining other devices to itself
- Does not route data
- Reduced Function Device
- Is typically battery operated

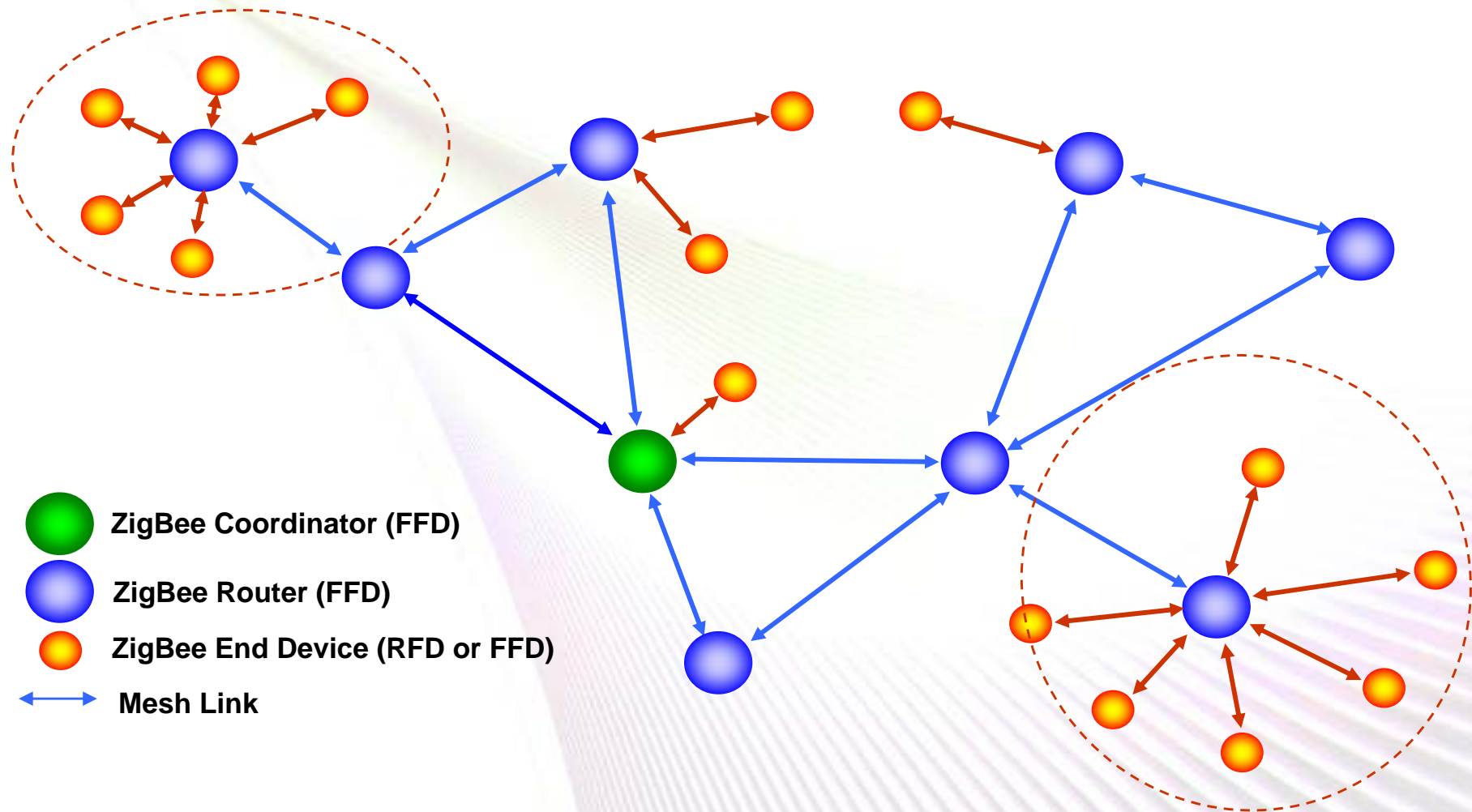
ZigBee Network Topologies (Star)



ZigBee Network Topologies (Tree)



ZigBee Network Topologies (Mesh)



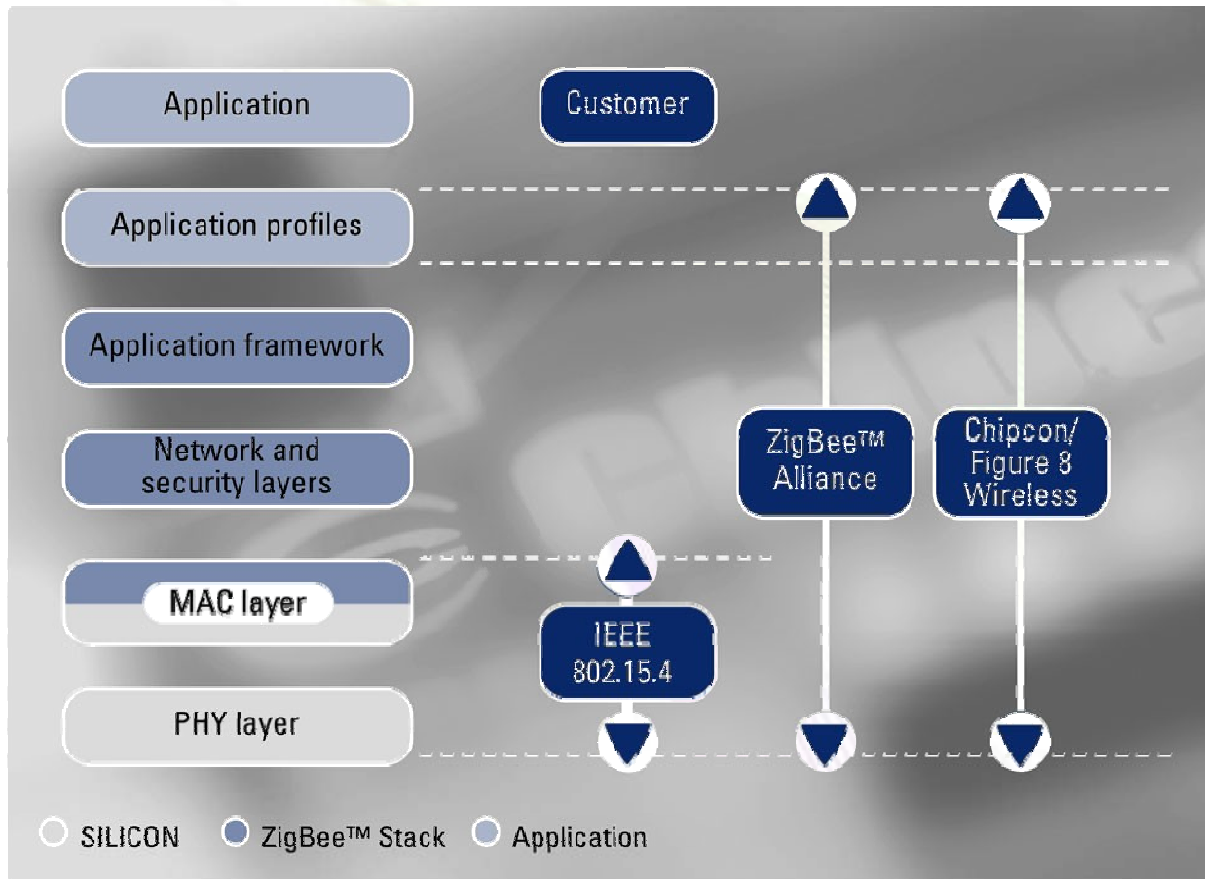
ZigBee Network Topologies

- **Star networks support a single ZigBee coordinator with one or more ZigBee End Devices (up to 65,536 in theory, < 2000 is realistic)**
- **Mesh network routing permits path formation from any source device to any destination device**
 - Radio Receivers on coordinator and routers must be on at all times.
 - Employs both, tree and table driven routing.
 - Table routing employs a simplified version of Ad Hoc On Demand Distance Vector Routing (AODV). This is an Internet Engineering Task Force (IETF) Mobile Ad Hoc Networking (MANET) submission.
- **Cluster tree networks provide for a beaconing multi-hop network**
 - Beaconing permits battery management of coordinator and routers.
 - Must tolerate high latency due to beacon collision avoidance.
 - Must use “netmask” type tree routing.

Addressing

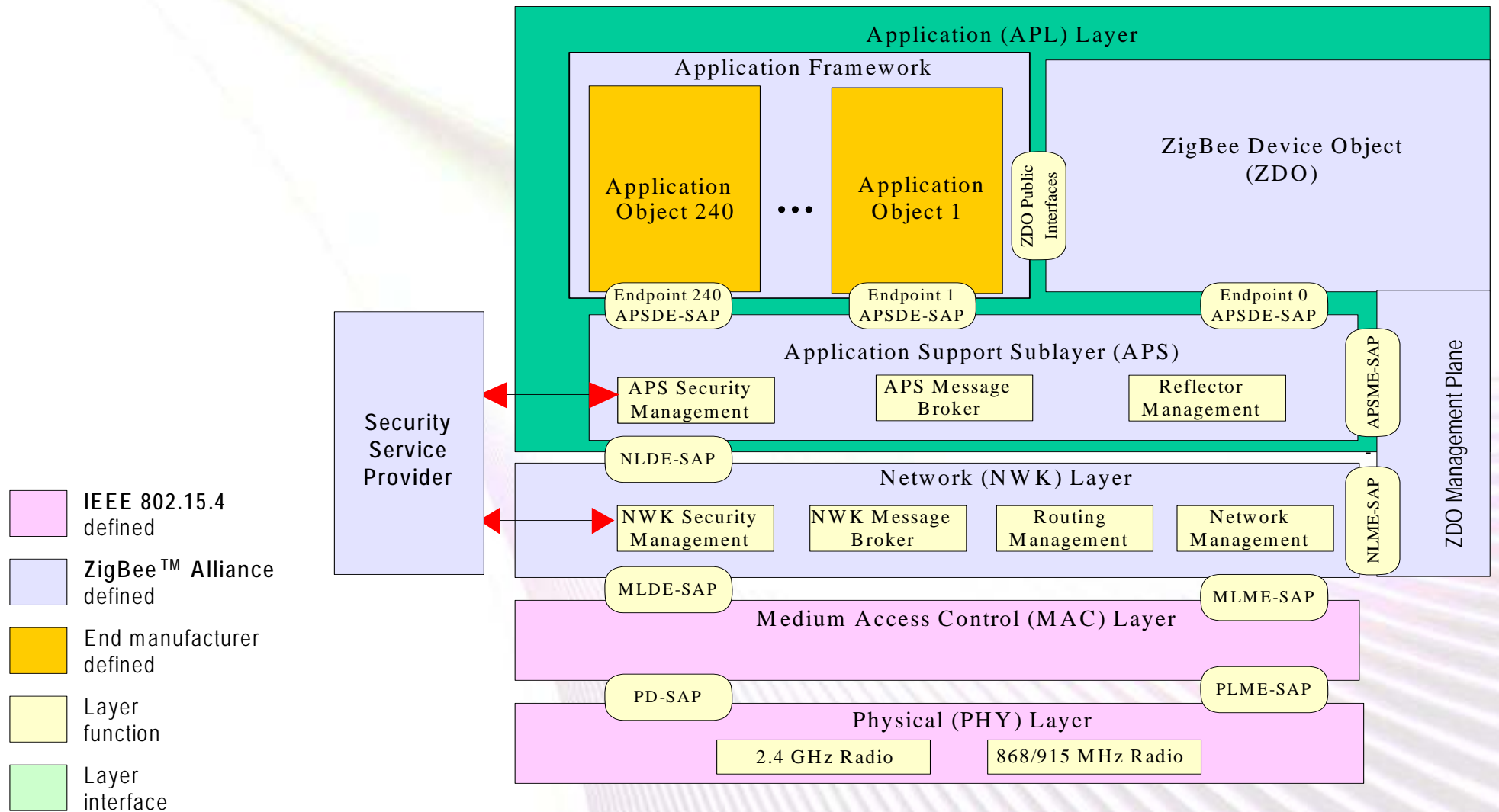
- **All IEEE 802.15.4 devices have a unique, 64-bit address, assigned during production.**
 - This long address is similar to the well-known MAC address used in a 802.11 wireless card or 802.3 Ethernet NIC card.
- **Each ZigBee device gets a short 16-Bit ZigBee address assigned during network formation.**
 - Similar the IP address in Ethernet
 - Makes in-network communications more efficient and substantially shortens the packet length. The PAN Coordinator is tasked with handing out the short address when a device joins its network.
- **CSkip based address assignment**
 - Assigns block of addresses to router to enable joining without intervention of Coordinator
 - Block size depends on max network depth

ZigBee™ – “One Stop Shop”



- **Hardware**
IEEE 802.15.4
compliant radios
CC2420/CC2430/
CC2431
- **Software**
ZigBee stack
“Z-Stack”
(Figure 8 Wireless)
- **Tools**
Development tools
Commissioning
Testing

ZigBee Stack Architecture



ZigBee compatibility

- **ZigBee with Standard Profile**

- Compatible with other vendor's devices (Vendor A "switch" works with vendor B "lamp")
- Already defined standard profiles:
 - 'Home Automation' (since September 2006, not backwards compatible to former 'Home Controls – Lighting')
 - 'Industrial Plant Monitoring' (since Q4 2006)
 - 'Commercial Building Automation' incl. HVAC (expected Q1 2007)
 - Much more in discussion (Automatic Meter Reading, Health Care, etc.)

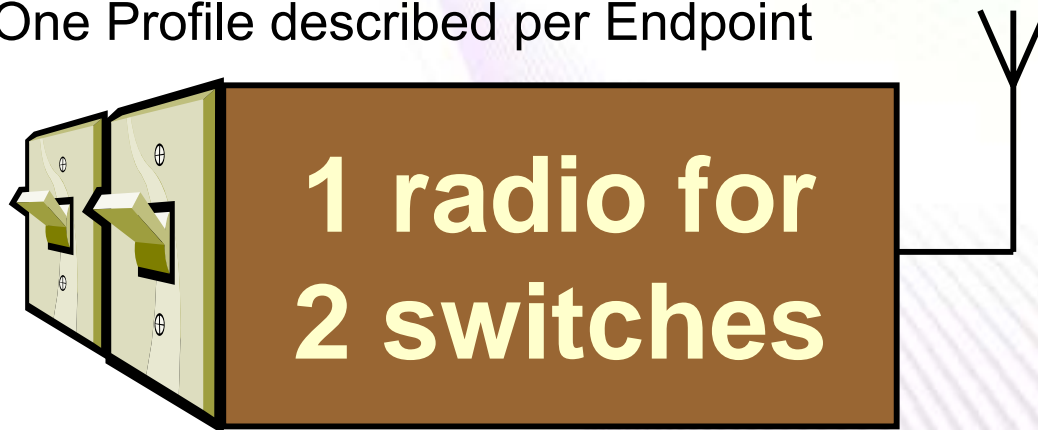
- **ZigBee with Proprietary Profile**

- Incompatible with other vendor's device
- Still can use infrastructure of an existing ZigBee network to transmit data packets (hopping)
- Has to be registered by ZigBee Alliance (already > 450 registered)

- **Conformance Certification (Platform and Logo)**

Endpoints

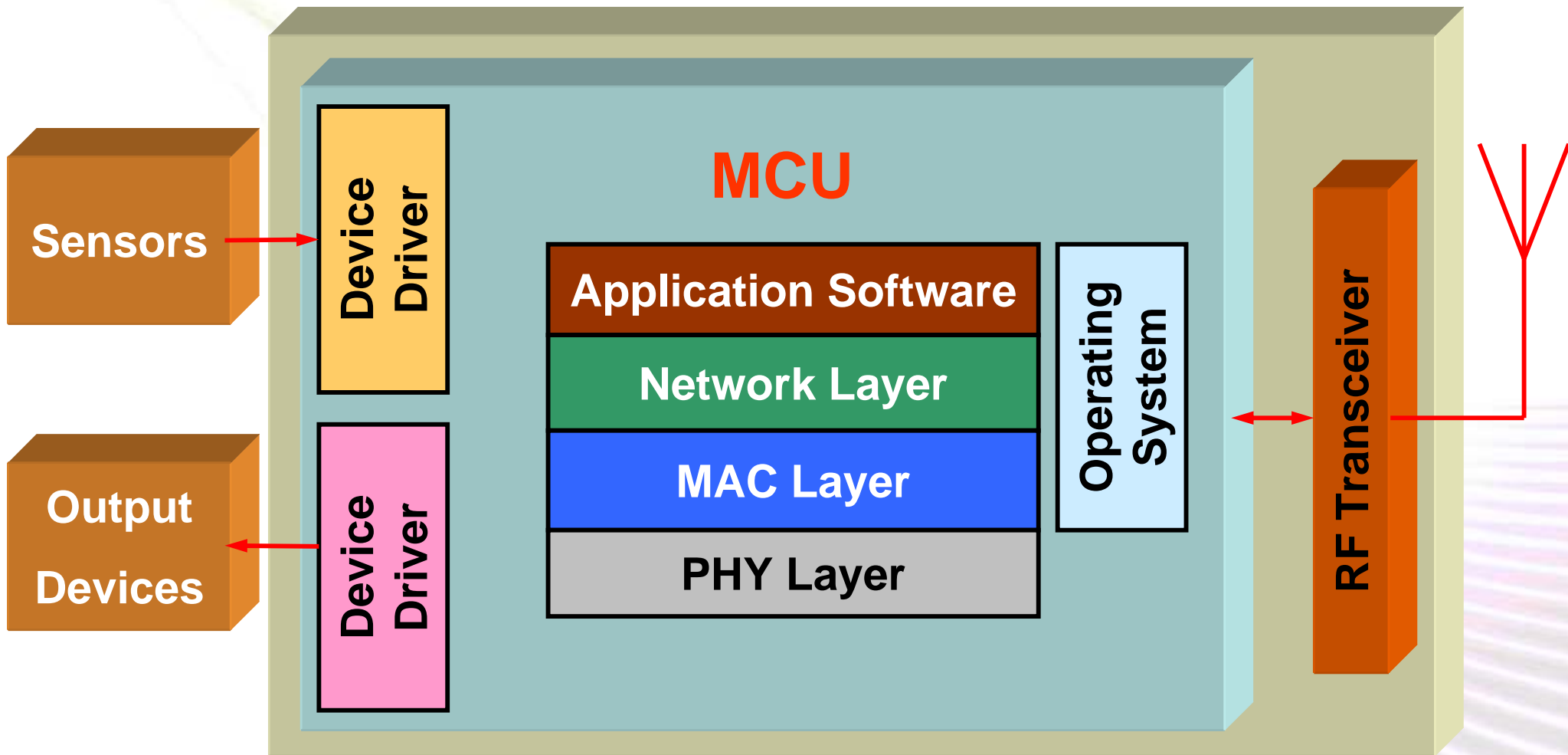
- **Endpoints are a logical extension added to a single ZigBee radio which permits support for multiple applications, addressed by the Endpoint number (1-240)**
- **Key Relationships:**
 - Maximum of 240 Endpoints per ZigBee Device (0 is reserved and used by ZDO (ZigBee Device Object) to describe the generic device capabilities. 255 is reserved for broadcasting to all endpoints, 241-254 are reserved for future use)
 - One Profile described per Endpoint



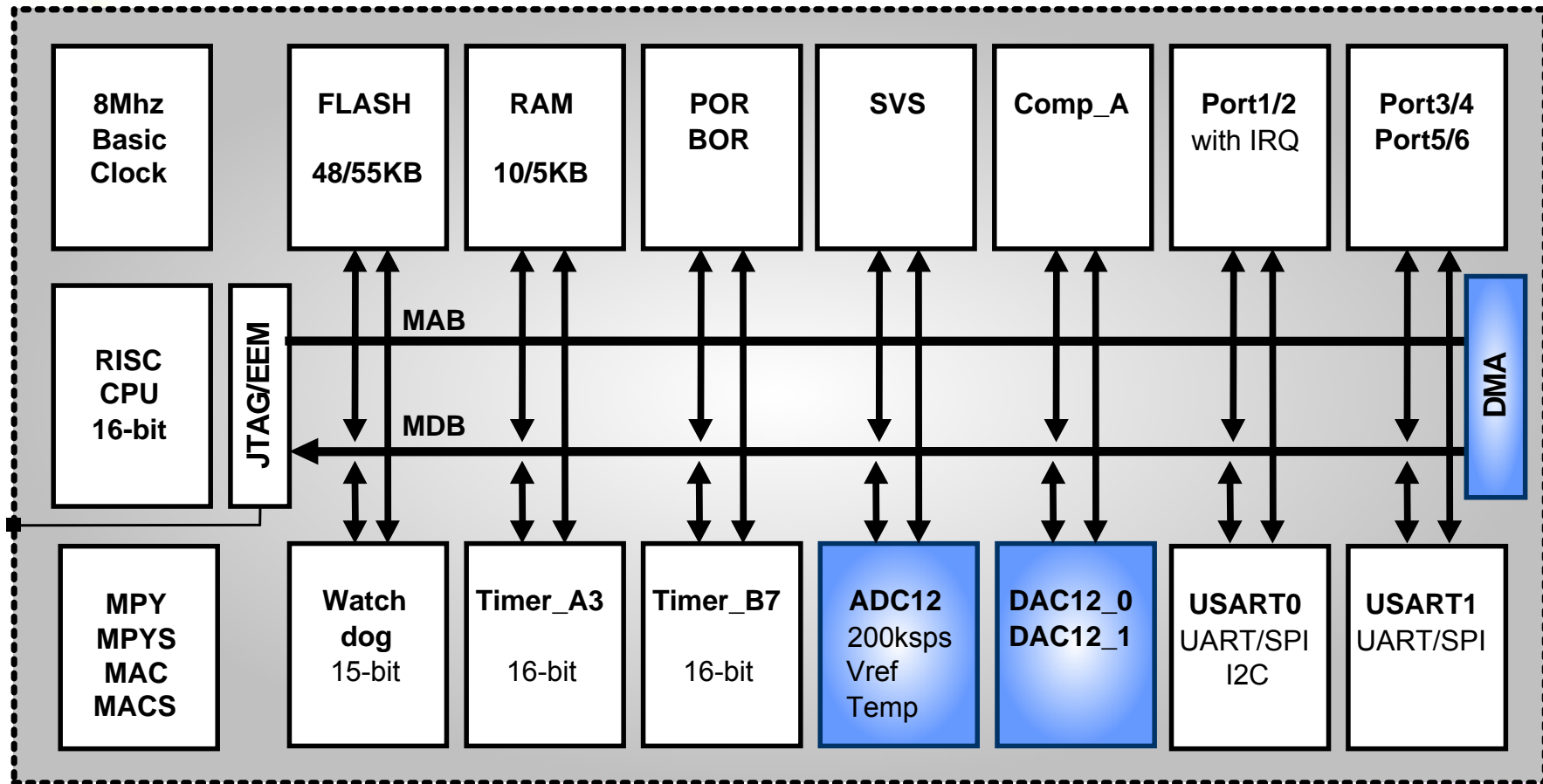
Agenda

- About 802.15.4 and ZigBee
- Introduction to ZigBee
- MSP430 802.15.4/ZigBee solutions
- Demonstration:
4-node ZigBee network application
- Application Design Considerations
- Facts, statistics & other information

ZigBee Device Block Diagram



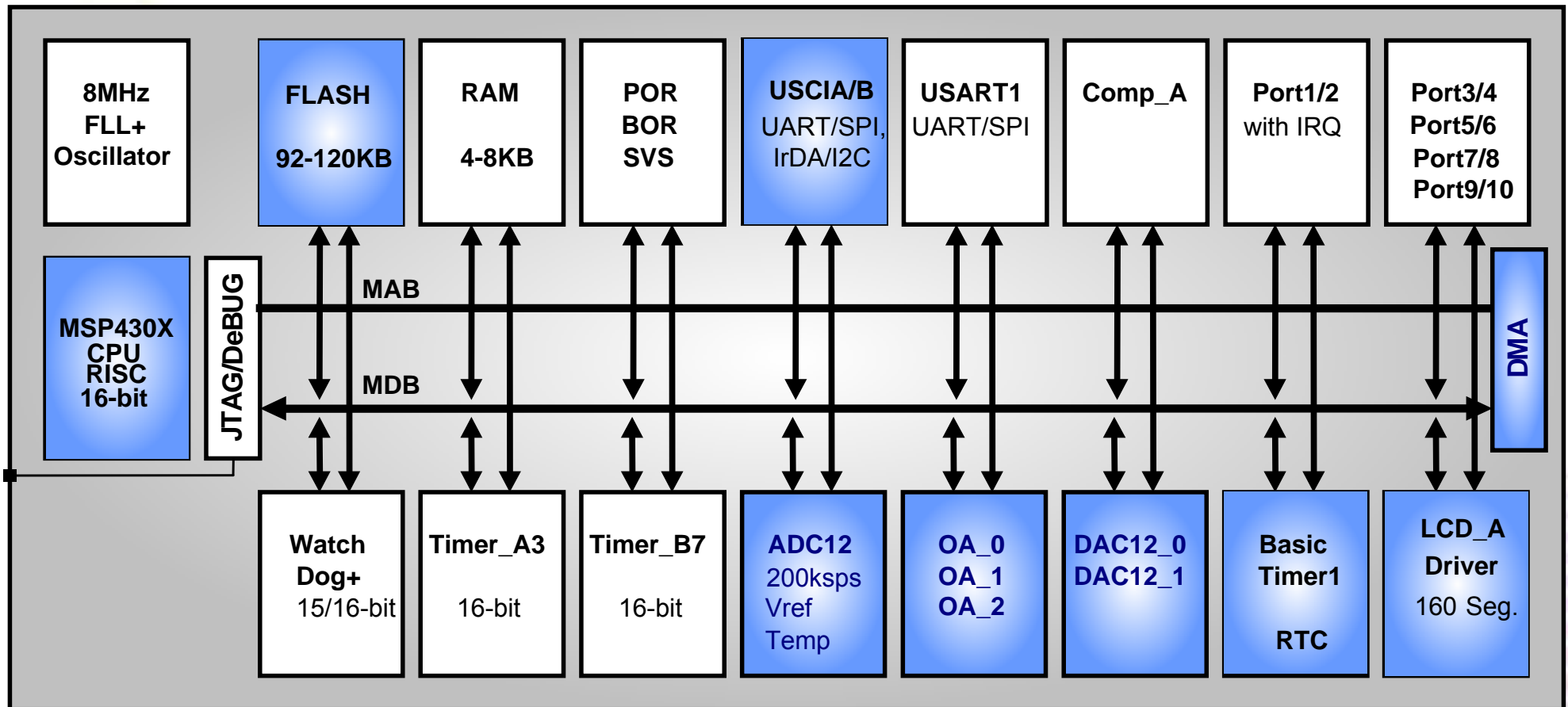
MSP430F161x: Good ZigBee Choice



- MSP430 48K or 55K Flash
- SCoC with ADC12, DAC12
- Maximum 10K RAM
- USART supports SPI, UART, and I2C

- ZigBee End Device
- Maybe ZigBee Router, application dependant

MSP430FG461x: Good ZigBee Choice

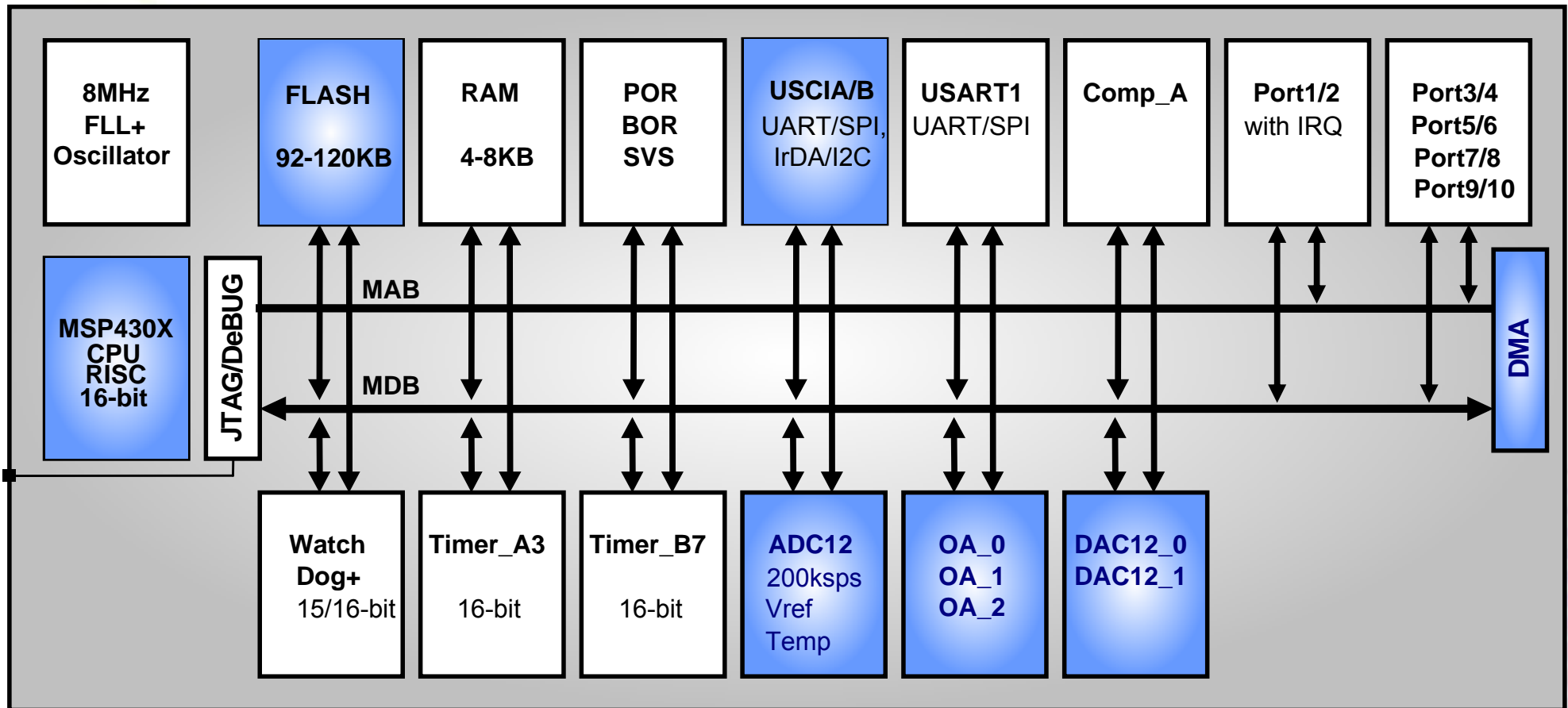


- 1st MSP430 with >60KB Flash
- Maximum 8K RAM
- SCoC with ADC12, DAC12 and OpAmps
- LCD_A with integrated charge pump
- USCI supports SPI, UART, I2C, LIN and IrDA

- ZigBee PAN coordinator
- ZigBee Router
- Complex ZigBee End Device

© 2006 Texas Instruments Inc, Slide 29

MSP430F261x: Good ZigBee Choice



- MSP430 with >60KB Flash
- Maximum 8K RAM
- SCoC with ADC12, DAC12 and OpAmps
- USCI supports SPI, UART, I2C, LIN and IrDA
- Planned for 2007

- ZigBee PAN coordinator
- ZigBee Router
- Complex ZigBee End Device

Chipcon Platform Generations

SmartRF[®]01
0.8 μm BiCMOS

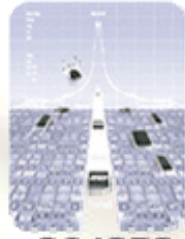


CC400
CC900

SmartRF[®]02
0.35 μm CMOS



CC1000
CC1050



CC1070
CC1020
CC1021



CC1010

SmartRF[®]03
0.18 μm CMOS



CC2400



CC2420



CC2430
CC2431

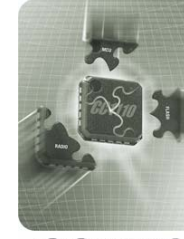
SmartRF[®]04
0.18 μm CMOS



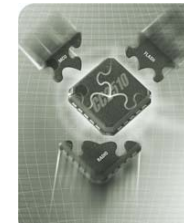
CC2500
CC2550



CC1100
CC1150



CC1110



CC2510

ZigBee



TI / Chipcon Solutions

- **Actual offerings**

- CC2420 – Z-Stack (1.4.0), 2.4GHz Transceiver
- CC2430 SoC – Z-Stack (1.4.0)
SoC with 8051 core, CC2420 radio and Z-Stack SW
- CC2431 SoC, is a CC2430 with location detection.
- IEEE 802.15.4 TIMAC
- MSP430/CC2430 ZigBee Stack – Z-Stack (1.5) – End of 2006
ZigBee software in CC2430 SoC, only application on MSP430
Low cost development kit, ideal to start with ZigBee.

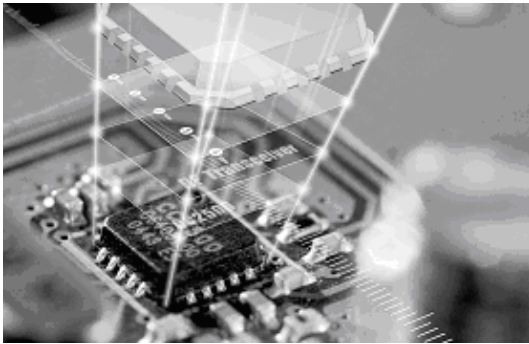
- **Upcoming Releases:**

- CC2520 IEEE 802.15.4 transceiver – 1H07
 - Similar to CC2420
 - Improved performance / feature set
 - Smaller package (5x5 mm QFN-28)
 - Reduced cost (TBD %) compared to CC2420
- CC2530 & CC2531 SoC
 - Next generation to CC2430 & CC2431

3 Ways to your ZigBee Application

MSP430 + CC2420
Ideal battery powered ZigBee End Device

1. Cost & Simplicity

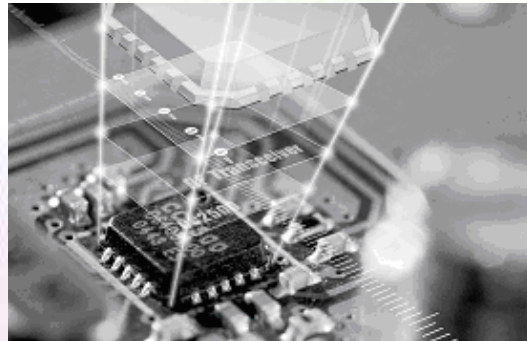


- CC2430 SoC for Application and ZigBee

2. Flexibility & Analog



+

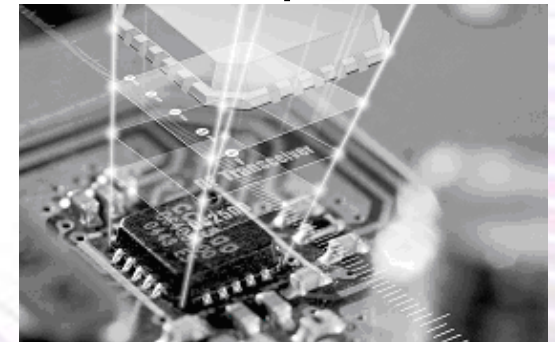


- MSP430 for Appl.
- CC2430 for ZigBee

3. ULP ZigBee



+



- MSP430 for Appl. & ZigBee
- CC2420 for RF

© 2006 Texas Instruments Inc, Slide 33

Develop a product for an existing Profile

1. Buy a development kit or module
2. Develop the application from existing profile demo software
3. Join ZigBee.org as Adopter
4. Pay Conformance Certification house for logo certification
5. Do FCC or CE certification
6. Produce and ship product

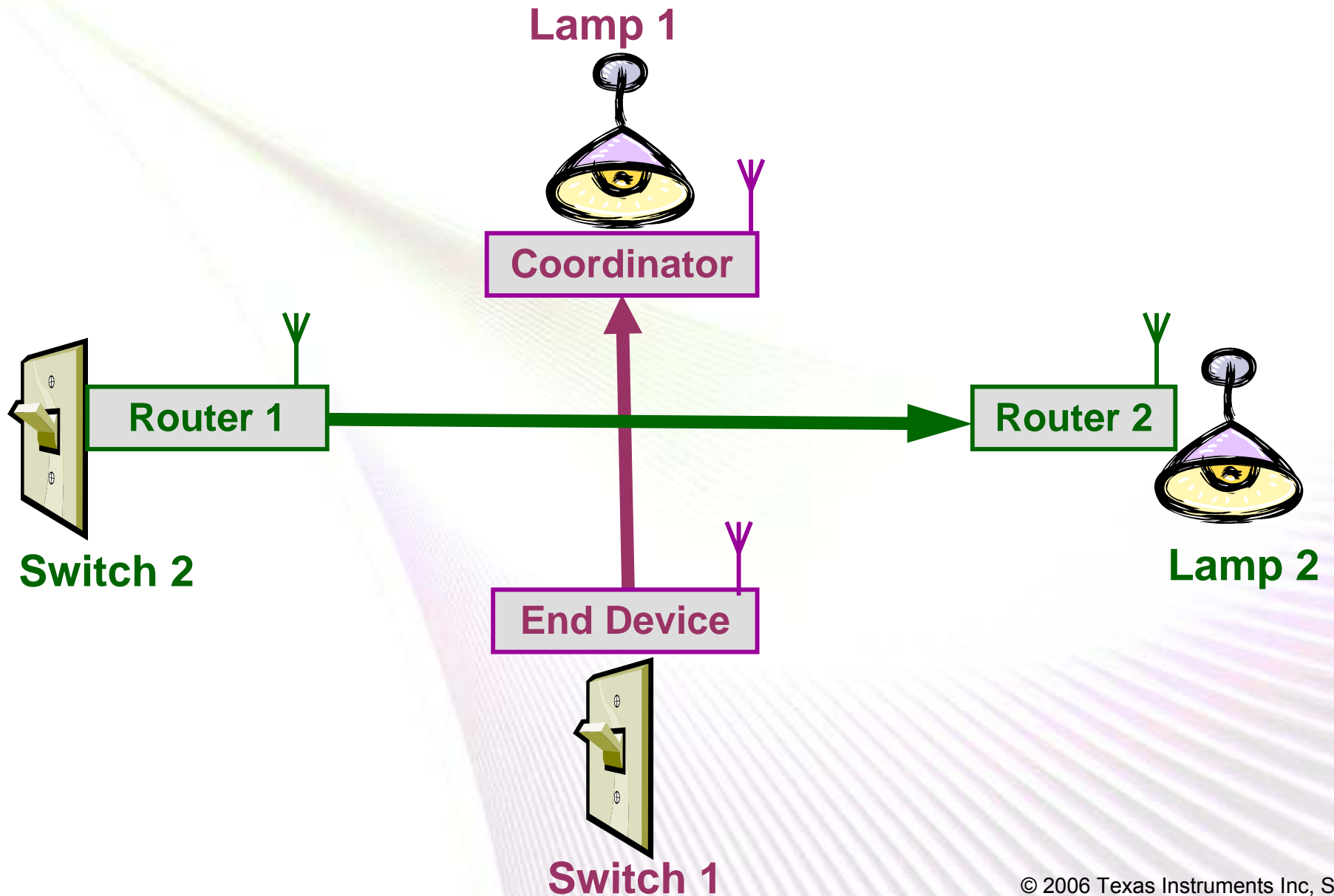


© 2006 Texas Instruments Inc, Slide 34

Agenda

- About 802.15.4 and ZigBee
- Introduction to ZigBee
- MSP430 802.15.4/ZigBee solutions
- Demonstration:
4-node ZigBee network application
- Application Design Considerations
- Facts, statistics & other information

Demo: 4-Node Network Application



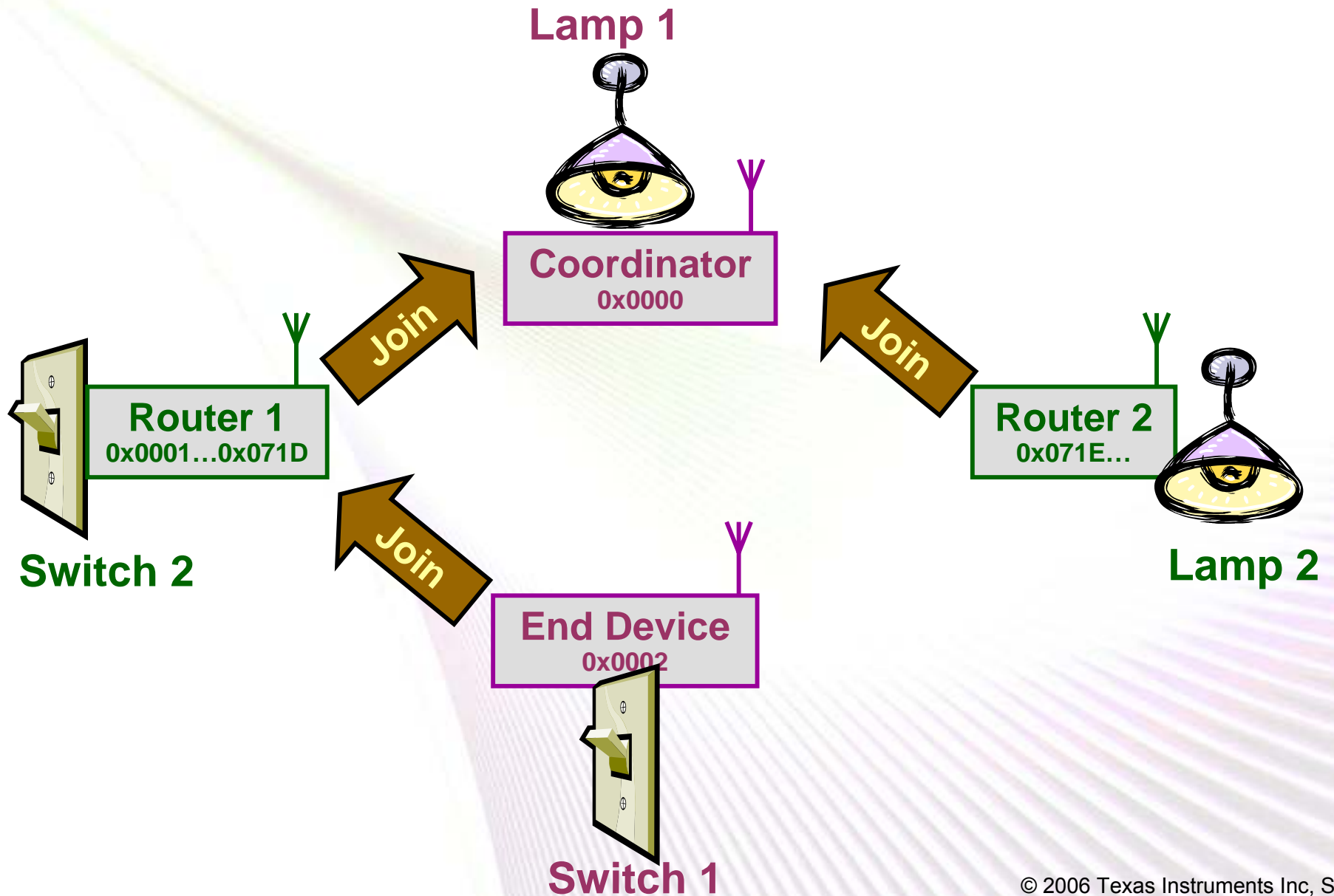
4-Nodes salient Features

- **ZigBee Network formation**
- **Devices association**
- **Application Binding**
- **Routing communication between devices**
- **“Sensing-and-acting” wirelessly
(On / Off control of a lamp using a switch)**
- **Self-healing / route repair**

Demo: Network Formation

- **Power up PAN Coordinator (P)**
 - PAN/C (P) sends beacon and starts network
- **Power up Router1 (R1)**
 - Router1 (R1) joins PAN Coordinator
 - PAN/C assigns R1 the ZigBee address 0x0001
 - R1 also gets a block of addresses (0x0001...0x071D) for further children to join R1
- **Power up Router2 (R2)**
 - Router2 (R2) joins PAN Coordinator
 - PAN/C assigns R2 the ZigBee address 0x071E
 - R2 also gets a block of addresses for further children to join R2
- **Power up EndDevice (E)**
 - EndDevice (E) joins Router1 (R1)
 - R1 assigns E the ZigBee address 0x0002

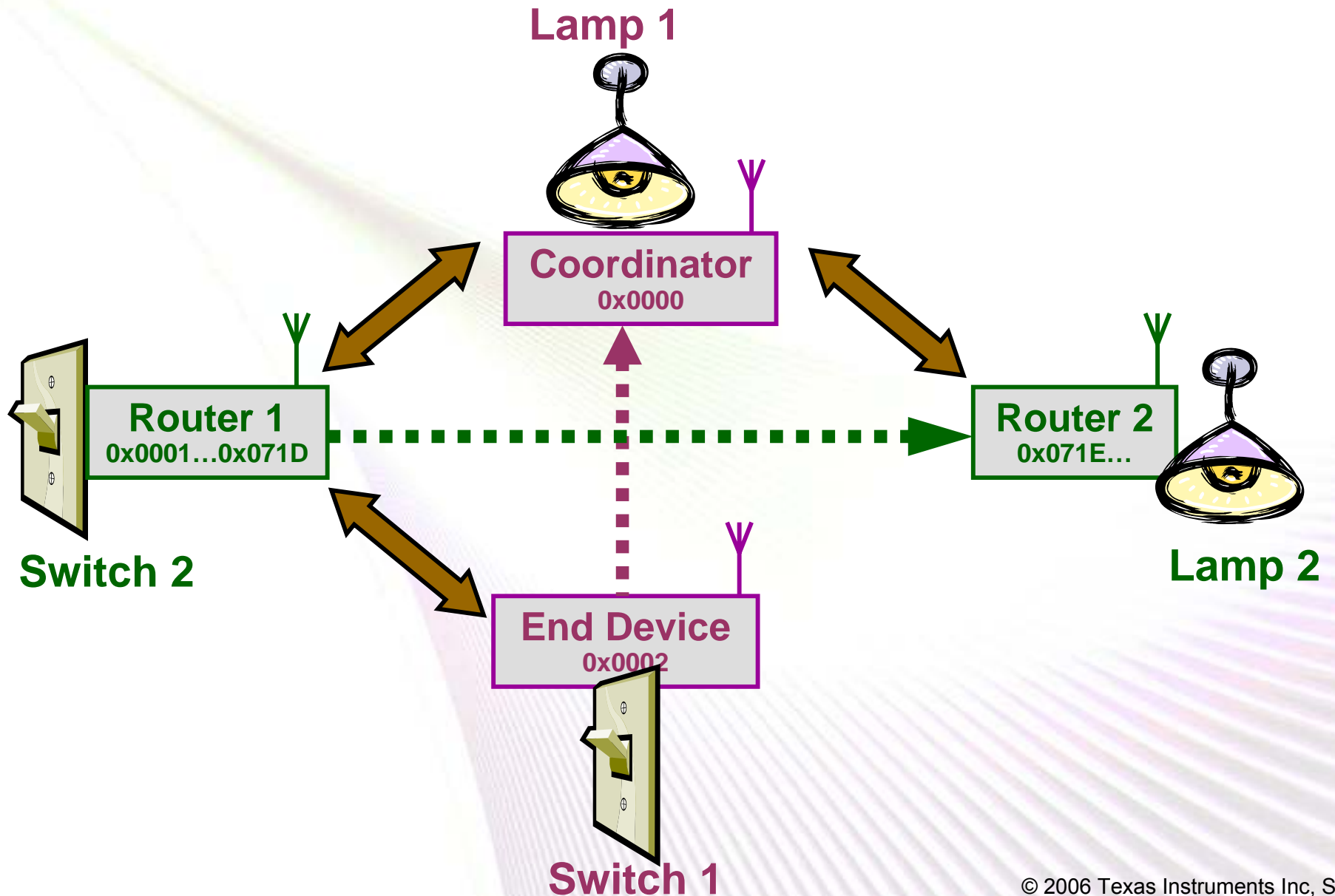
Demo: Network Formation



Demo: Application Binding

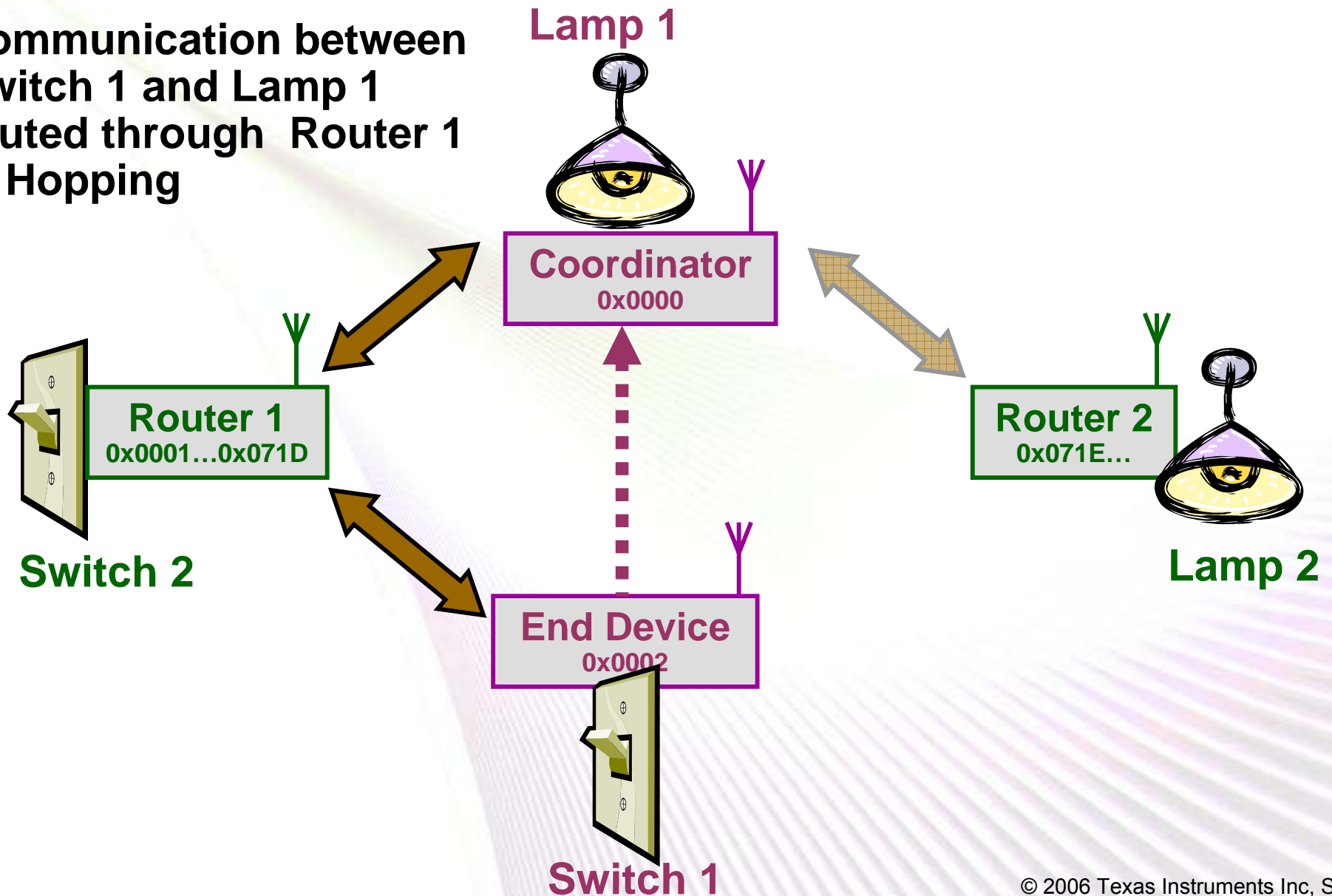
- **Switch 1 will be bound to Lamp 1**
- **Switch 2 will be bound to Lamp 2**
- **Binding is done in this demo during network formation**

Demo: Application Binding



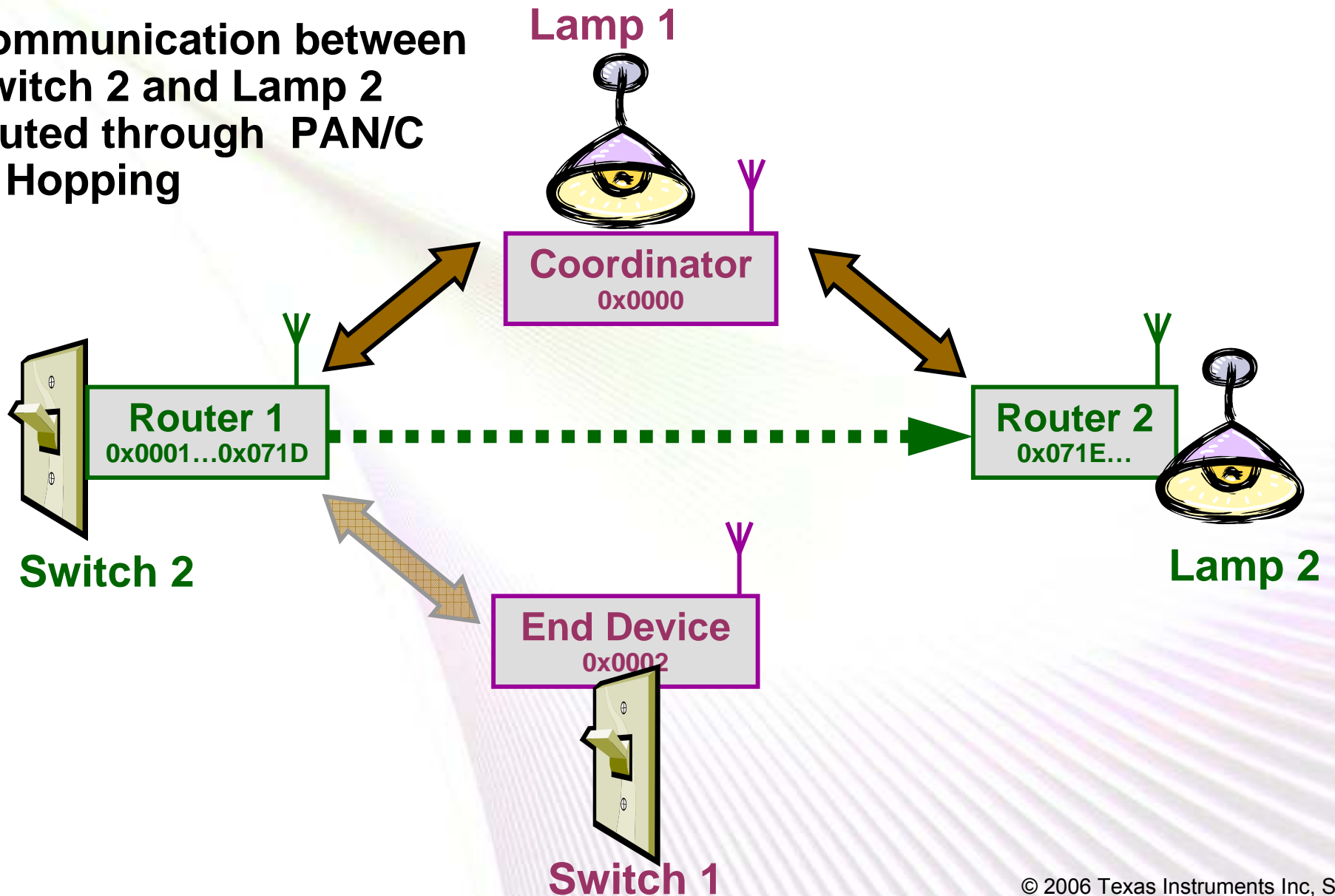
Demo: Communication (1)

Communication between
Switch 1 and Lamp 1
routed through Router 1
⇒ Hopping



Demo: Communication (2)

Communication between
Switch 2 and Lamp 2
routed through PAN/C
⇒ Hopping

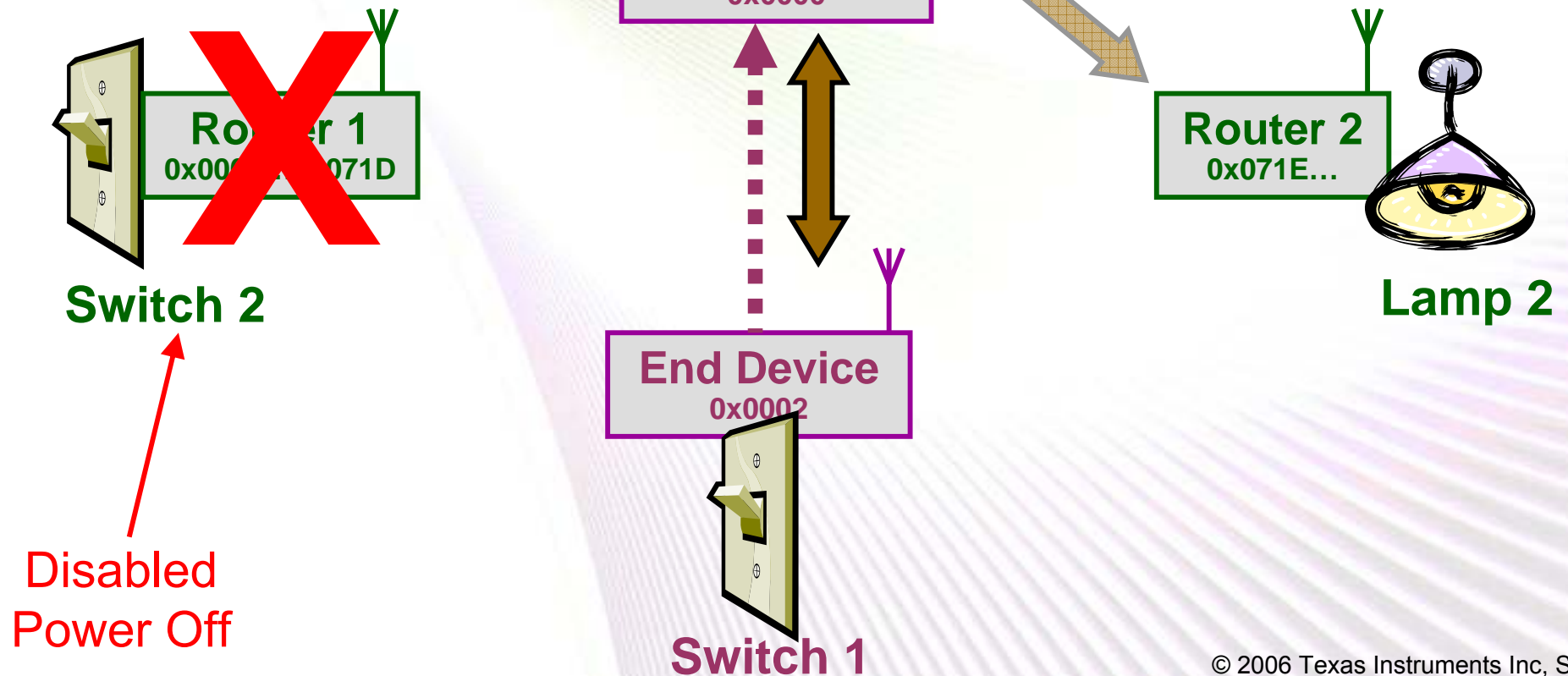


© 2006 Texas Instruments Inc, Slide 43

Demo: Self healing (scenario 1)

Automatically takes alternative route.

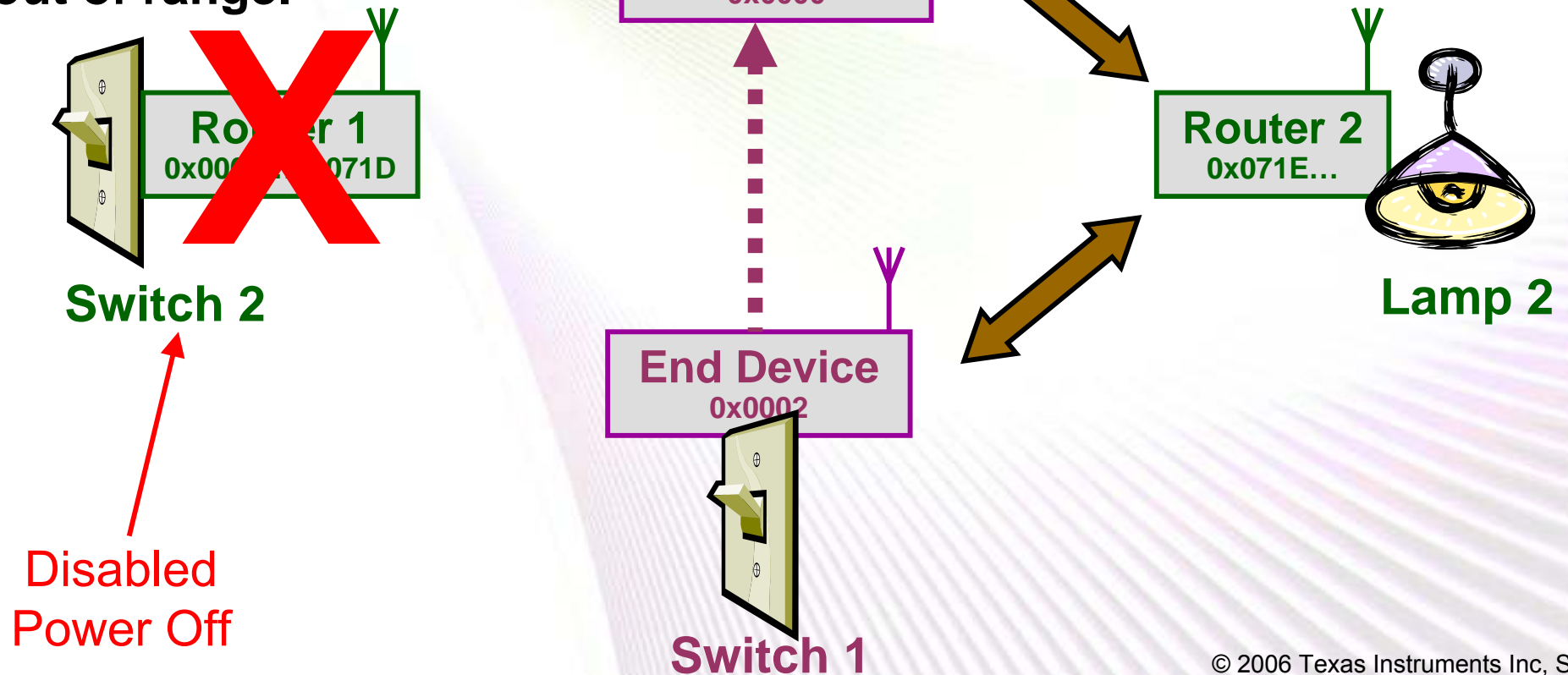
Switch 1 communicates direct to Lamp 1, if it's within range.



Demo: Self healing (scenario 2)

Automatically
takes alternative route.

Switch 1 communicates
through Router 2
(hopping), if Lamp 1 is
out of range.



Agenda

- About 802.15.4 and ZigBee
- Introduction to ZigBee
- MSP430 802.15.4/ZigBee solutions
- Demonstration:
4-node ZigBee network application
- Application Design Considerations
- Facts, statistics & other information

Application Design Considerations

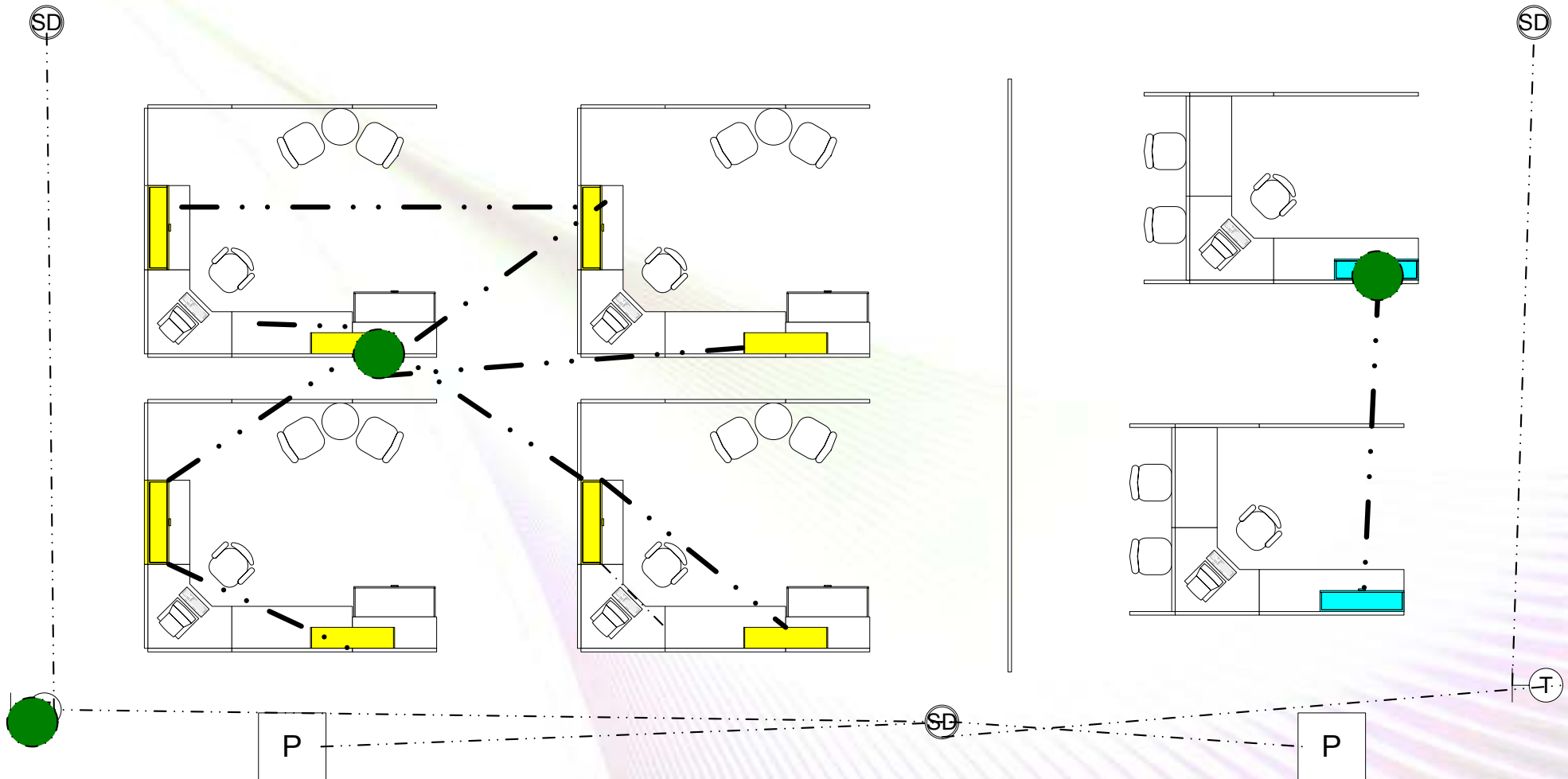
Network Formation Management

- Permit Join can be enabled/disabled on routers and the coordinator (network wide)
- Permit Join can be managed by an application to allow devices to enter the network upon:
 - Button press on a designated device or any other application defined action
 - Security keys may be exchanged upon managed network formation
- Deployment examples:
 - No commissioning tool
 - Example: Bubble pack purchased at a home improvement store
 - Commissioning tool
 - Example: Professional installation

Commissioning without Tool

Suite 101

Suite 102



- **Three networks: Suite 101, Suite 102, Fire Safety for the floor**
- **Coordinators are the green dots** ●
- **Question: How to commission appropriate devices to their proper coordinators**

© 2006 Texas Instruments Inc, Slide 48

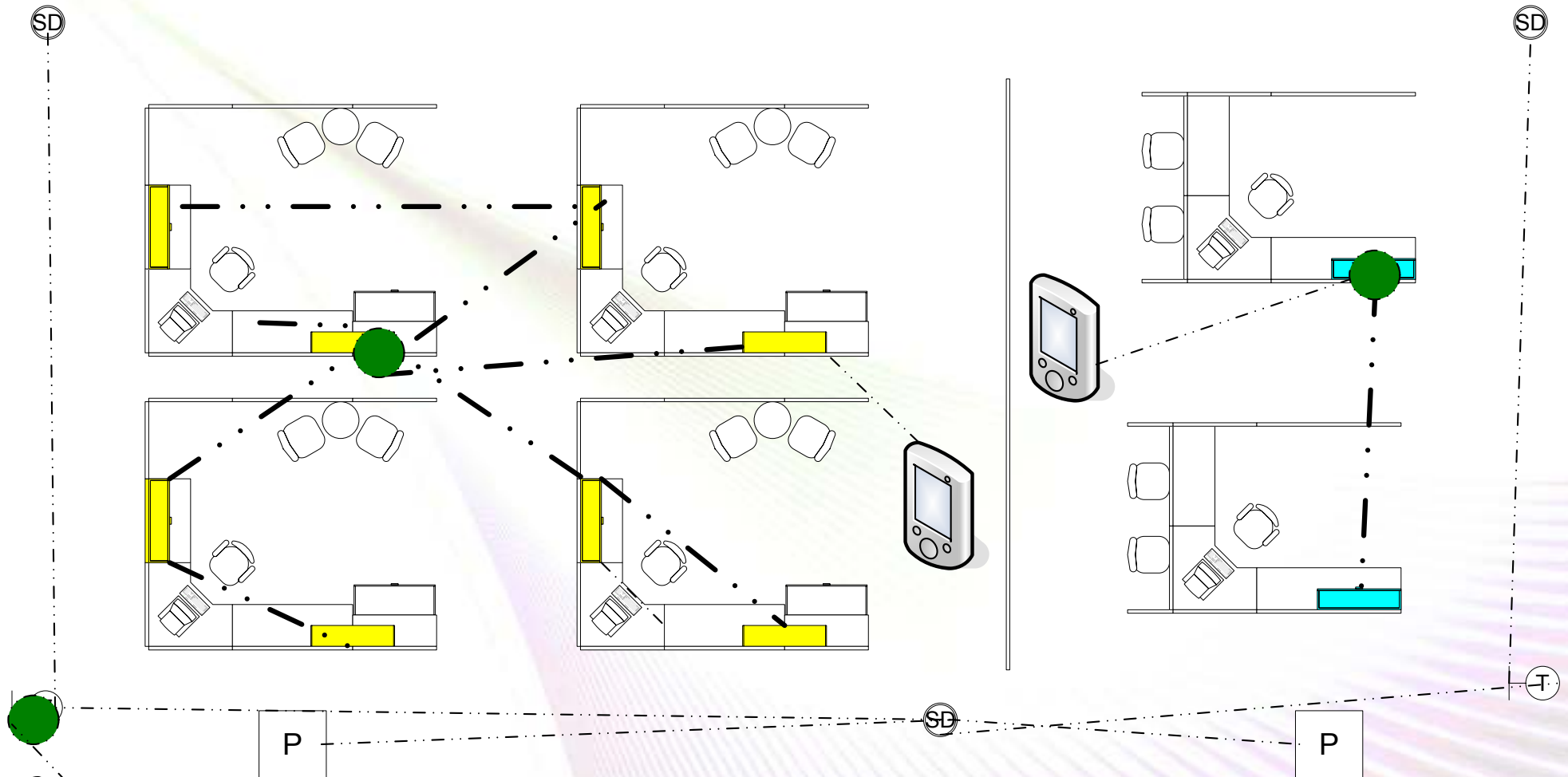
Commissioning without Tool

- **Some approaches to the previous commissioning problem (without a dedicated commissioning tool):**
 - Button press sequences to permit joining for a set amount of time and then a second set of button presses to identify the joining devices
 - Low power output
 - Reduces RF transmission distance to ,one suite‘
 - Though this may affect the topology if the end device children are too far away from their parent
 - Remote control device selection
 - Choose all neighbors and then iterate through deducing which device is which
 - Construct the list and permit the user to add/eliminate devices
 - Pre-manufactured with information on devices in the pack

Commissioning with Tool

Suite 101

Suite 102



- Same network topologies as before with addition of commissioning tools
- Commissioning tool works by identifying neighbors and networks, joining appropriate network, populating a list of devices on the network and permitting the installer to identify which one is which

© 2006 Texas Instruments Inc, Slide 50

Agenda

- About 802.15.4 and ZigBee
- Introduction to ZigBee
- MSP430 802.15.4/ZigBee solutions
- Demonstration:
4-node ZigBee network application
- Application Design Considerations
- Facts, statistics & other information

ZigBee cost

- **IEEE Addresses for 802.15.4**

- 240 addresses ~1800 \$

- **ZigBee Alliance**

- Promoter 40.000\$/year
- Member 9.500\$/year
- Adopter 3.500\$/year

- **ZigBee Logo**

- Conformance Certification (Platform and Logo)
e.g. TÜV (world wide: <http://www.tuv.com/>)
NTS = National Testing Systems
(world wide: <http://www.ntscorp.com/about/locations.html>)

- **RF Compliance Tests**

- FCC
- ETSI
- CE

Z-Stack for MSP430 + CC2420

- **Coordinator**

- k bytes of CODE memory – Flash program memory
- bytes of DATA memory – RAM
- bytes of CONST memory – Flash memory

- **Router**

- k bytes of CODE memory – Flash program memory
- bytes of DATA memory – RAM
- bytes of CONST memory – Flash memory

- **End Device (Reduced Function)**

- bytes of CODE memory – Flash program memory
- bytes of DATA memory – RAM
- bytes of CONST memory – Flash memory

Summary

ZigBee:

- **Software Stack on top of IEEE 802.15.4**
- **Standardized**
- **Low cost**
- **Low power consumption**
- **Long battery life**
- **Low data rate**
- **Easy installation**
- **Available today from Texas Instruments**

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		Applications	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
RFID	www.ti-rfid.com	Telephony	www.ti.com/telephony
Low Power Wireless	www.ti.com/lpw	Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2007, Texas Instruments Incorporated