RTLS Overview:
Active RFID

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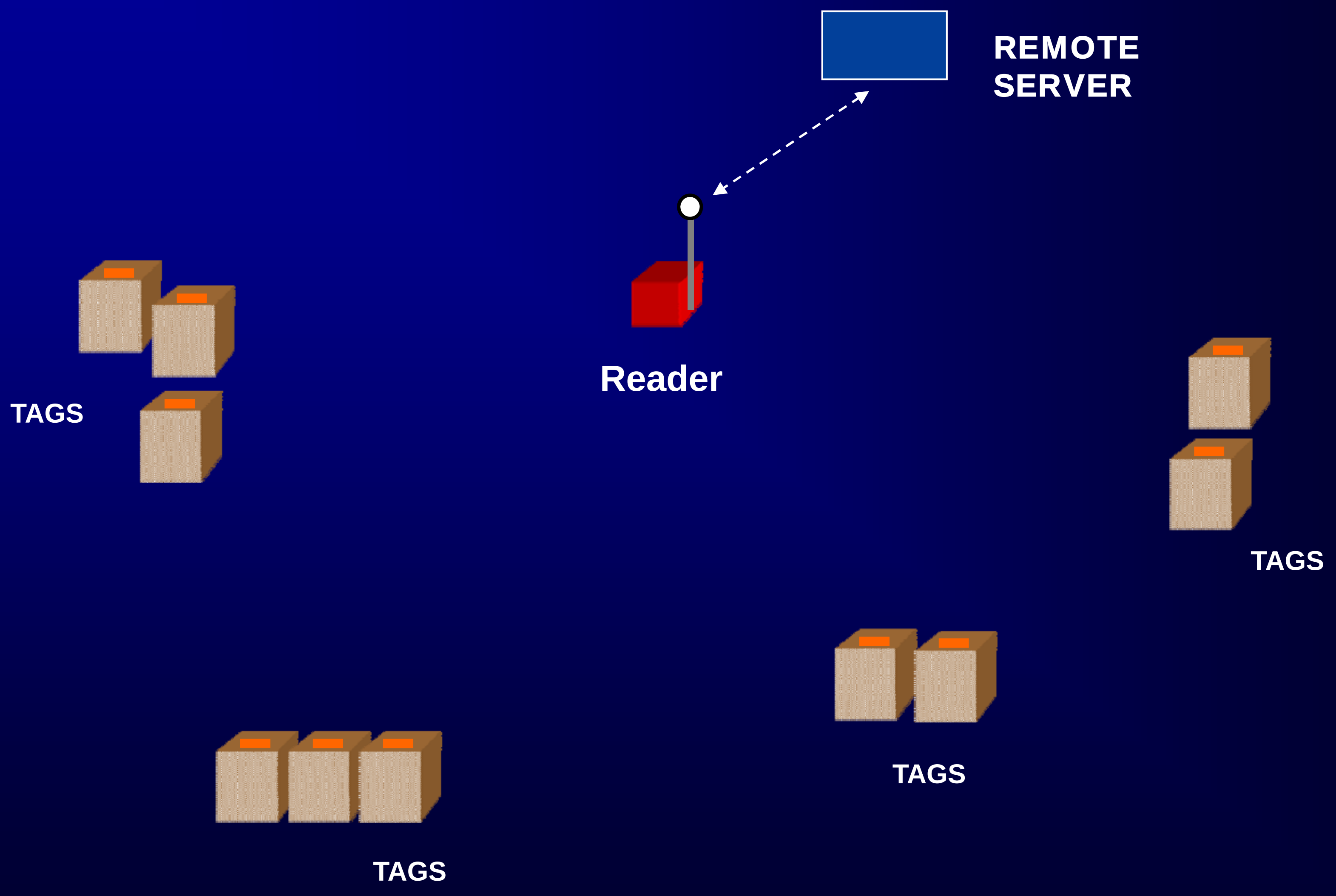
Outline:

- Active RFID RTLS Overview
- UWB vs Coherent
- Technologies and Standards
- Propagation Issues for coherent
- Emerging Approaches for RTLS

Common RFID Requirements

- Perfomance: accuracy
- Low-Cost
- Reliability
- Long battery life
- Long communication range (10m-100m)
- Low data rate is OK
- Anti-collision (TDMA, CSMA, etc) needed for applications with large tag populations
- Conformance with Industry standards for applications that are not closed loop
- optional: Mesh capability
- Security has increasing importance

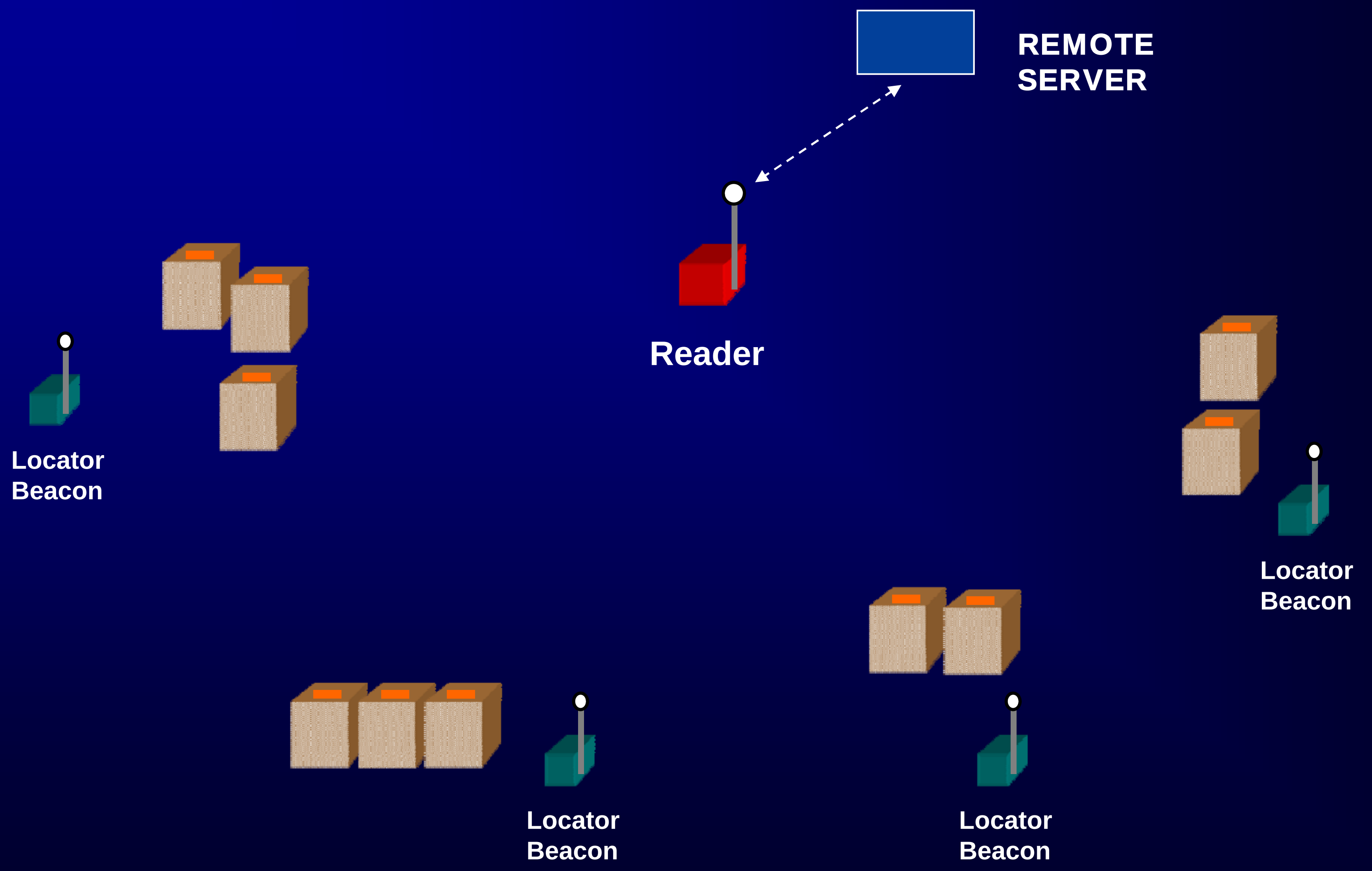
Sample RTLS Architecture



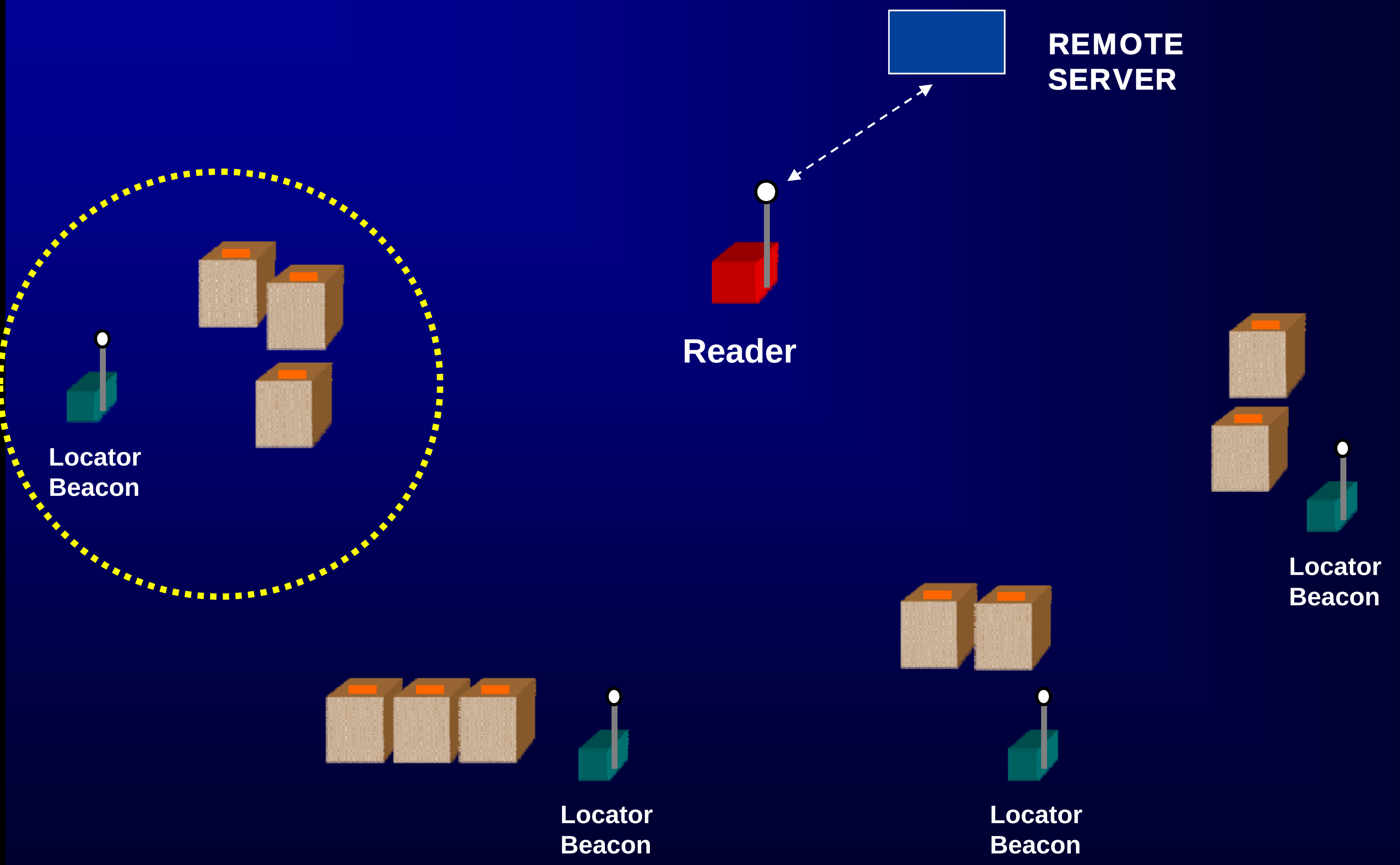
Approach #1: “Discretized” RTLS

- Use multiple readers or beacons
- Divide problem into read zones
- Disadvantage: does not provide continuous Pos.

“Discretized” RTLS Architecture



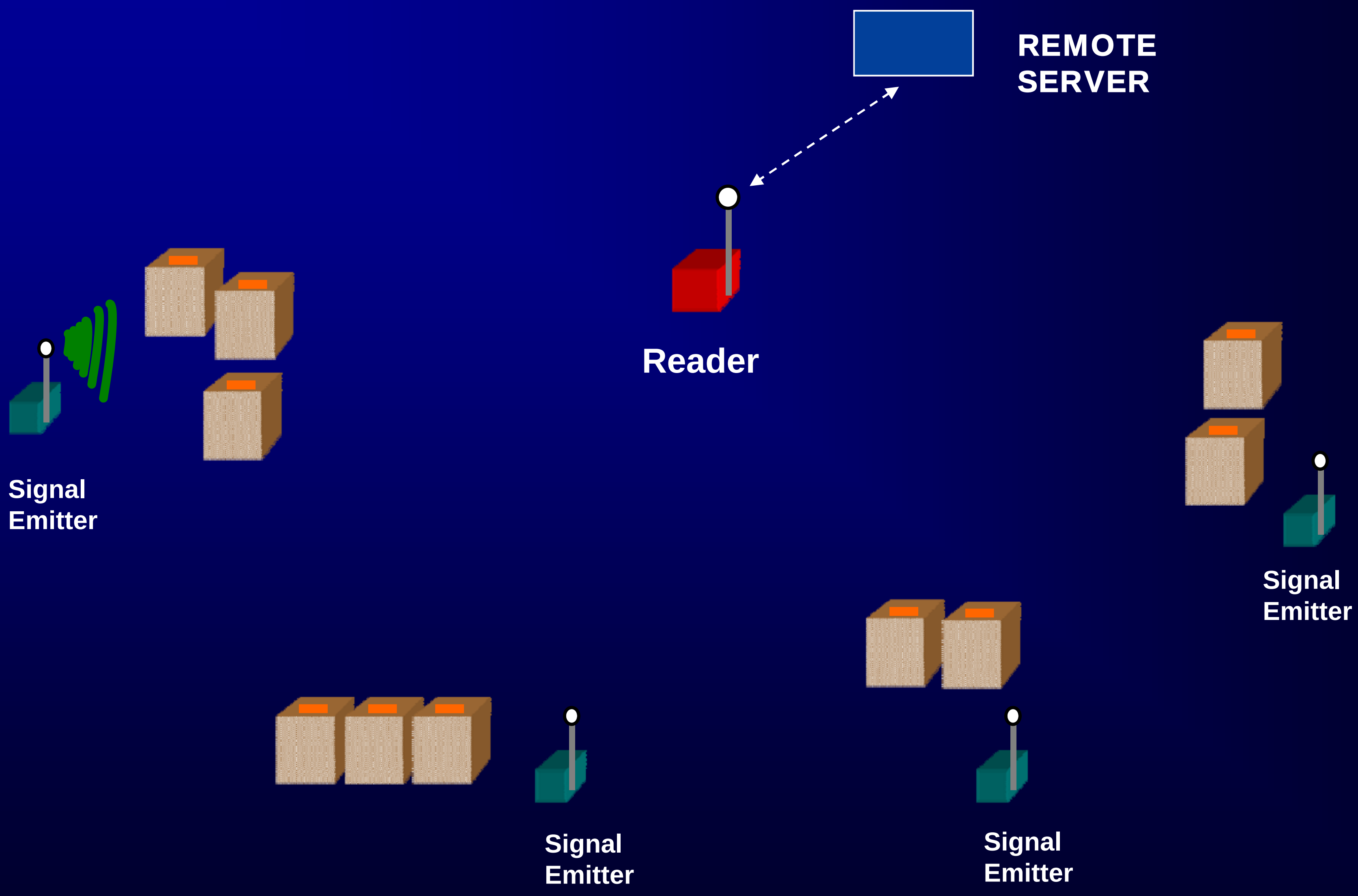
“Discretized” RTLS Architecture



Approach #2: “Out of Band” Sensors

- Use separate signal to do positioning
- Examples: ultrasound, Infrared, other carrier
- Disadvantage: requires sensor on tag

“Out of Band” Sensor Positioning



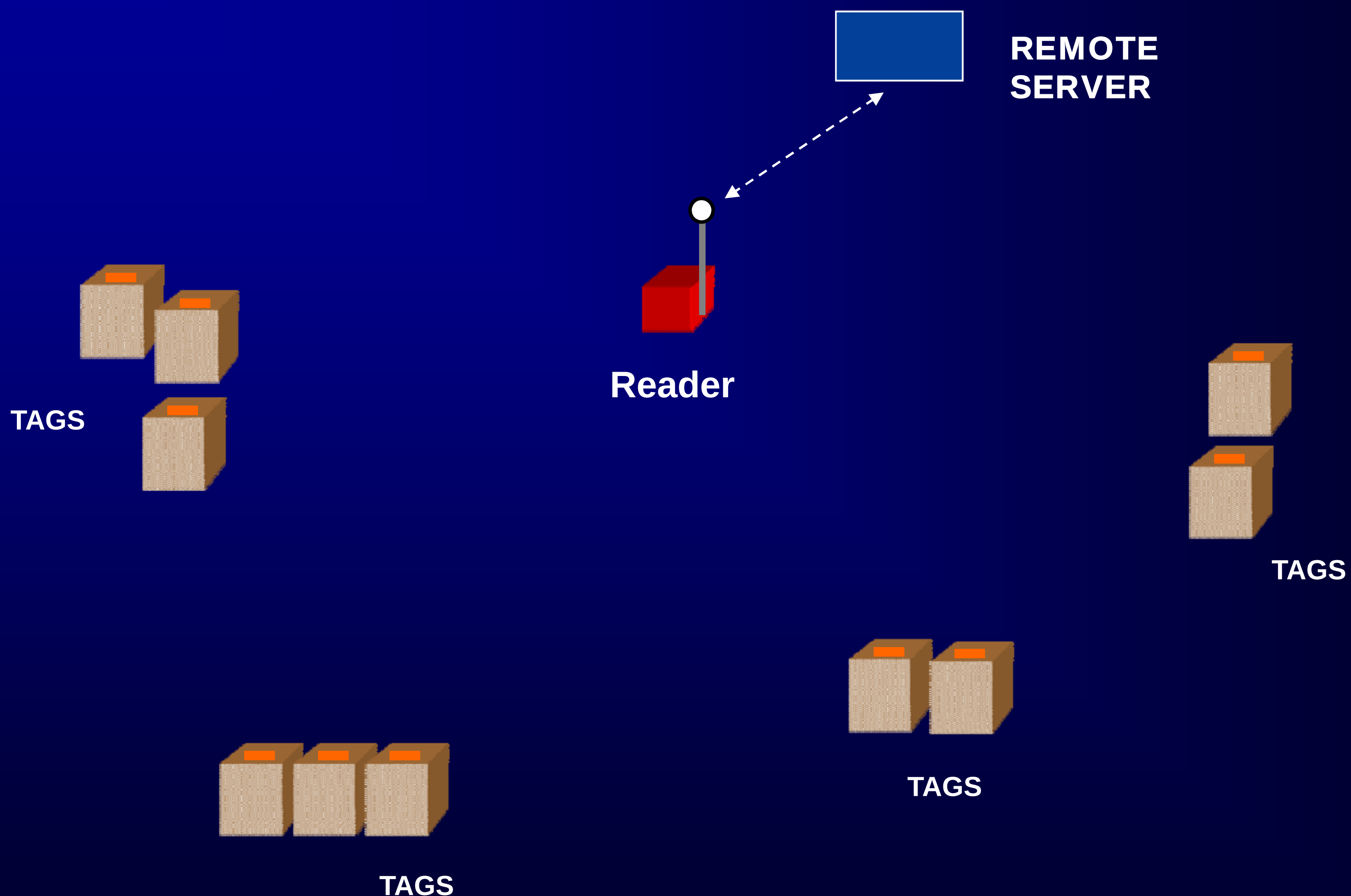
Approach #3: “Pure” RTLS

- Use multiple readers
- Use only available observable signals

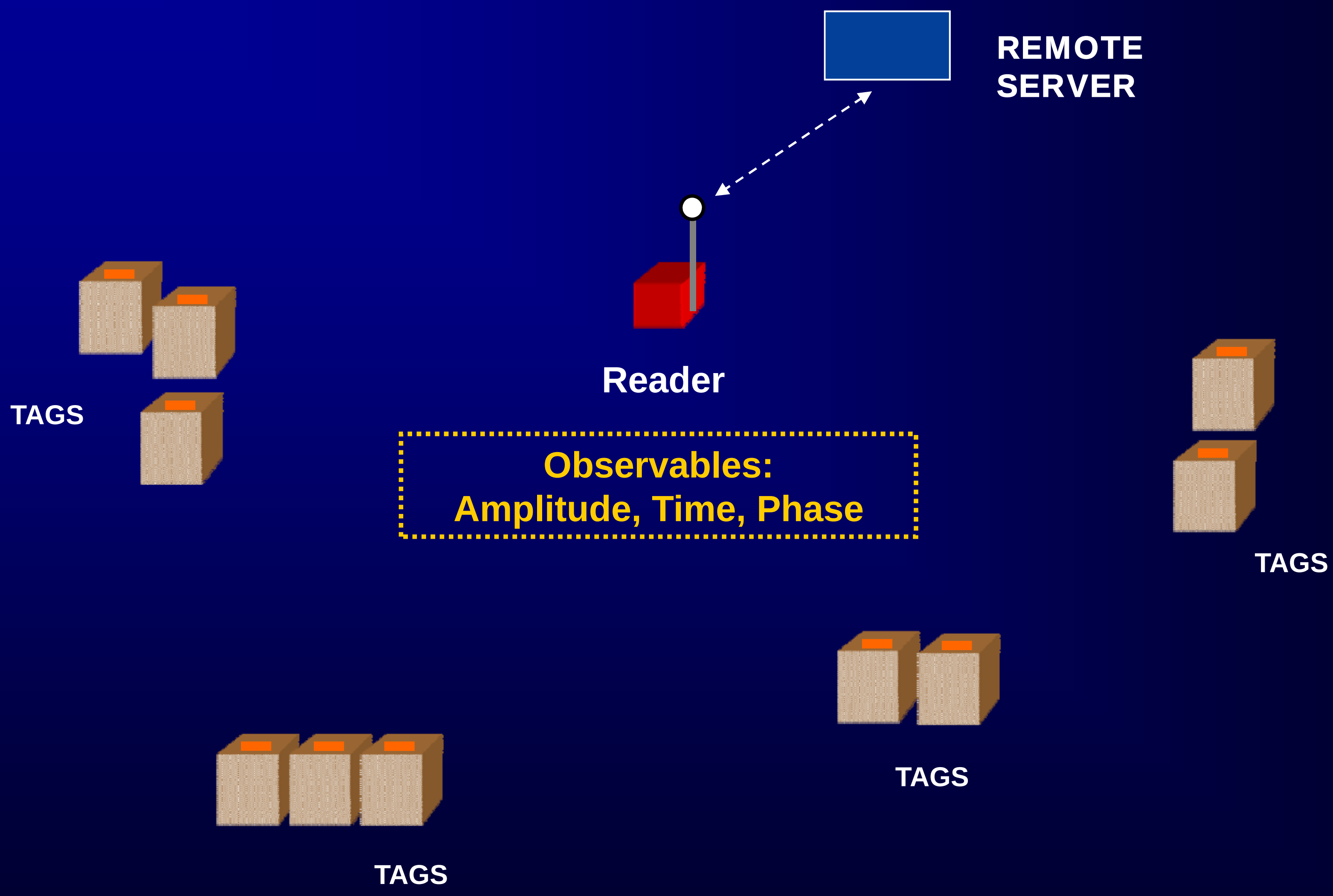
Challenges:

- Dynamic environments
- Real-time?

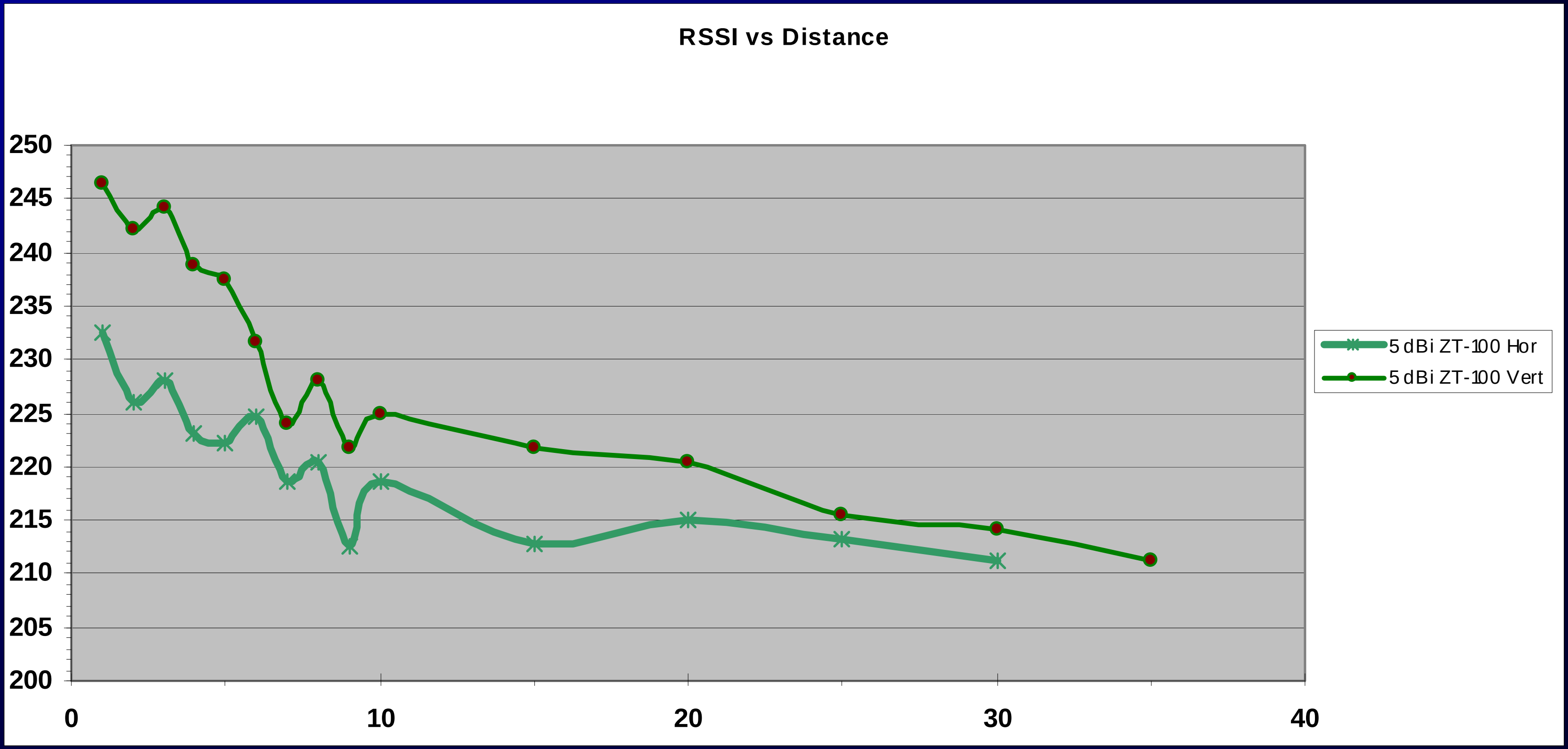
“Pure” RTLS Architecture



RTLS Observables

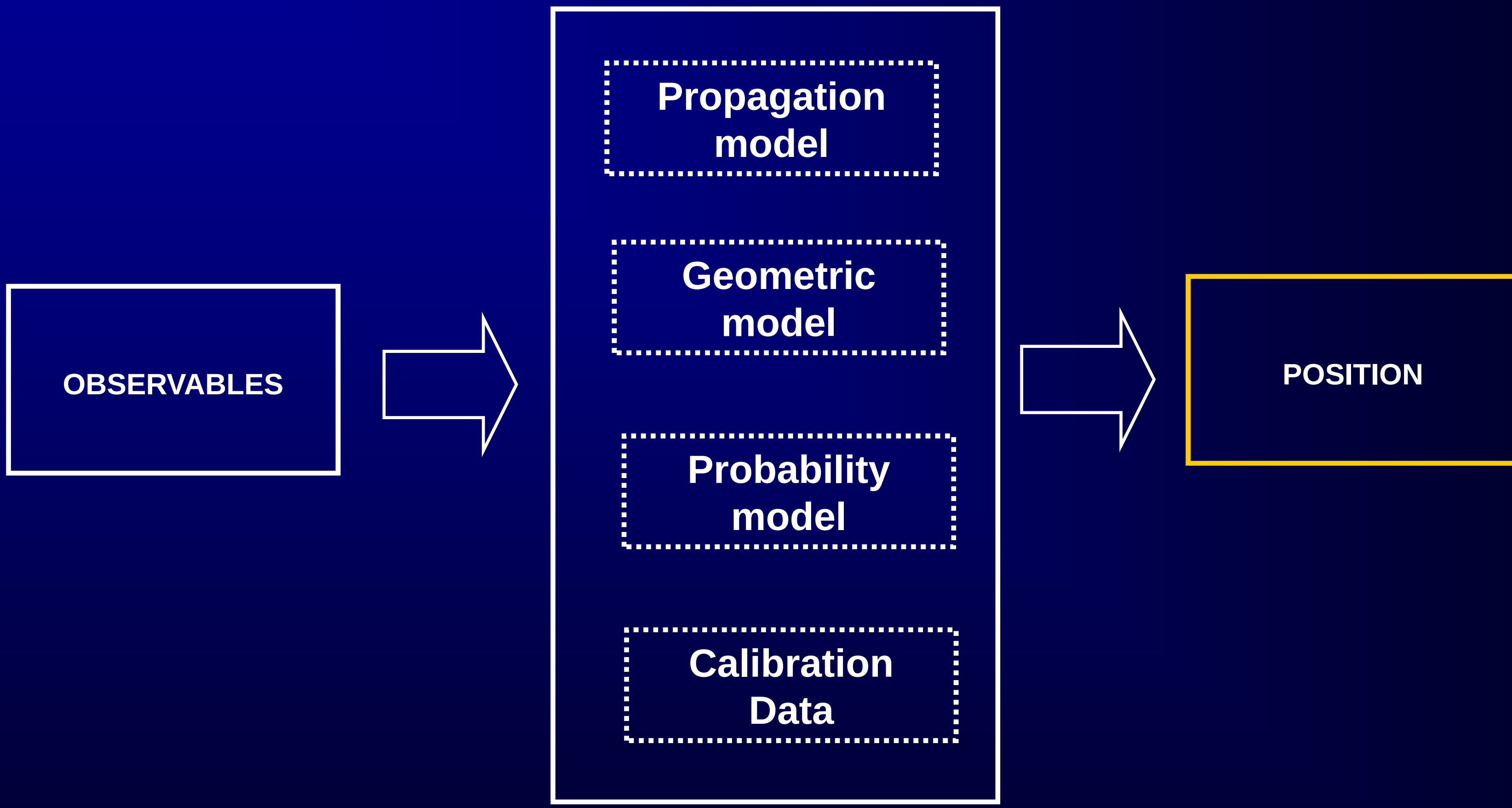


The Challenge: sample data



- signals not monotonic with position

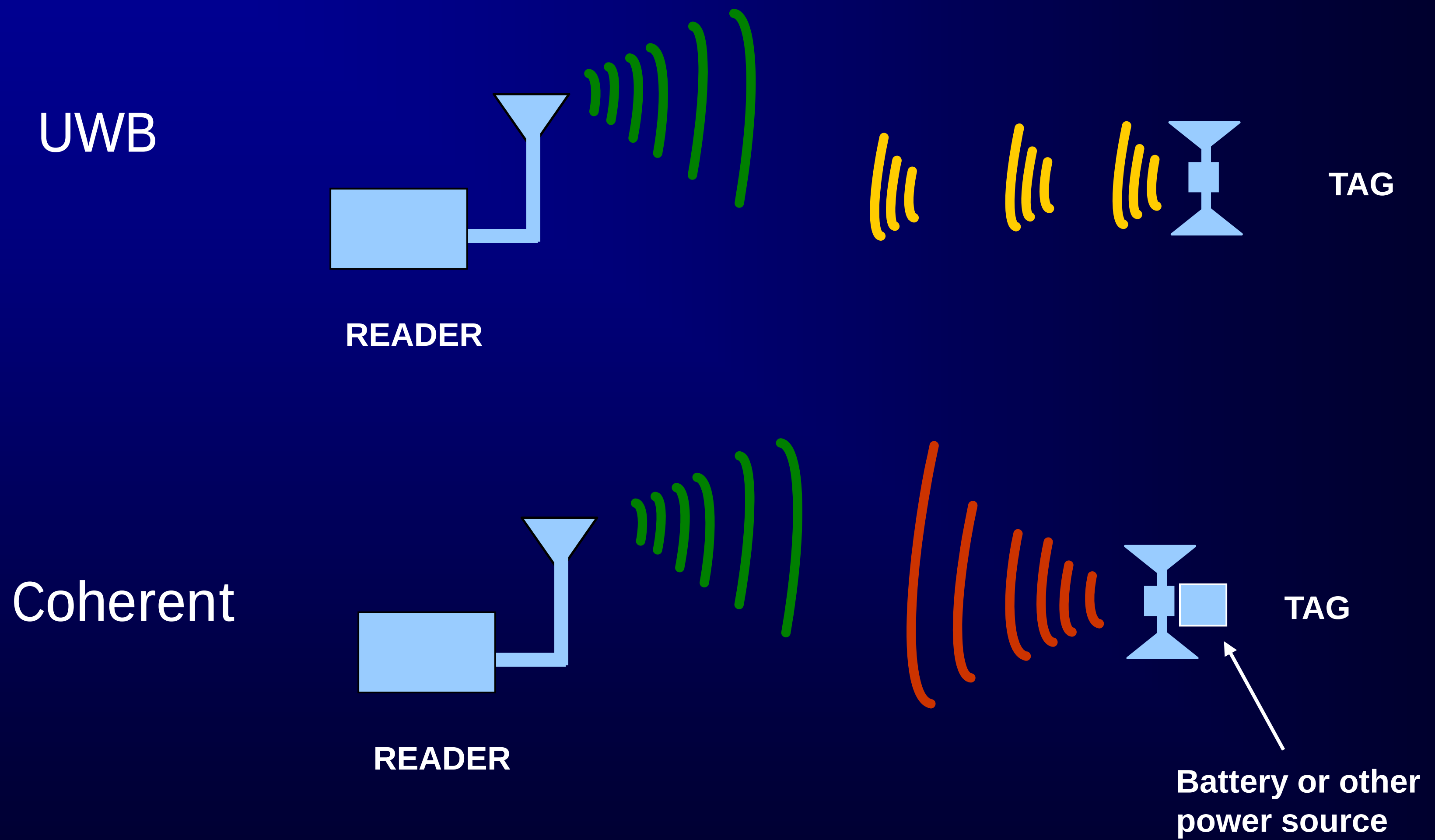
General Approach



RTLS Model

Technologies and Standards

Active RFID Categories



Ultra-Wide Band

UWB

Relevant observables: time, amplitude
Challenges: dispersion, RX sensitivity, regulation

IEEE 802.15.4a - UWB

- Commercial Vendors (sample)
  - Ubisense
  - Multi Spectral Solutions
  - Parco Wireless
  - Time Domain

- Advantages
  - Low power
  - Good data rate (but still less than 1Mbps)
  - resistant to interference
  - Precise positioning using TOA (10 cm accuracy)

- Disadvantages
  - Shorter range than narrowband frequency domain radios
  - Standardization efforts IEEE 802.15.4a and 802.15.3a (W-USB) have not been very successful
  - UWB Frequency standards vary around the world

Coherent Transmission

Coherent
(e.g. DS-SS)

Relevant observables: amplitude (RSSI), phase
Challenges: multi-path

“Coherent-Active” Standards

Several Competing Standards:

- ISO 18000-7 (Savi)
- IEEE 802.11 (WLAN)
- IEEE 802.15.4 (Zigbee, WPAN)
- (Bluetooth 802.5.1 not considered due to master-slave protocol model)
- Others (ISO)

IEEE 802.11 (WLAN)

- Advantages
  - Popular, open and active standard
  - Long communication range
  - Robust security features
  - Existing access points and routers can be configured as readers
  - Native multi-hop capability will become available in 2008 when 802.11s standard is ratified
  - Spread spectrum physical layer
  - Emerging standard for Real Time Location (RTLS): ISO/IEC 24730-2
- Disadvantages
  - Higher cost
  - Higher power consumption in general
  - Impact of large tag population on Wi-Fi networks unclear (IP address allocation, 802.11a/b/g/n/s network impact)
  - Still requires moving/installing access points/readers for RTLS

ISO 18000-7 (Savi)

- Advantages
  - Designed specifically for active RFID (1990)
  - Dominant in military/govt market
  - Signals at 433 MHz have better penetration through dielectrics than higher frequencies
  - worldwide acceptance for 433 MHz
  - 32-bit UID plus user memory
- Disadvantages
  - Longer wavelength (λ=0.7m) – Not preferred for indoor use or metal enclosures
  - Low bandwidth – bit rate = 27.7 Kbps
  - very basic support for security (4 byte password)
  - Reader-Talks first communication, random time-slotted anti-collision
  - Requires License (Savi/Lockheed)

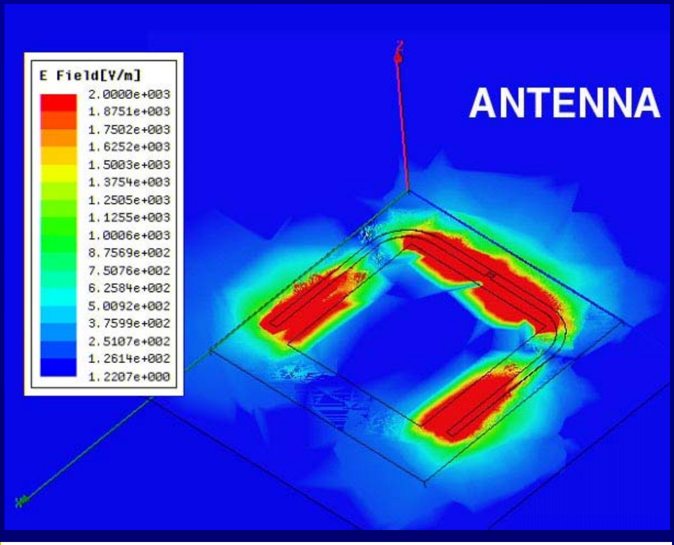
IEEE 802.15.4 Tags

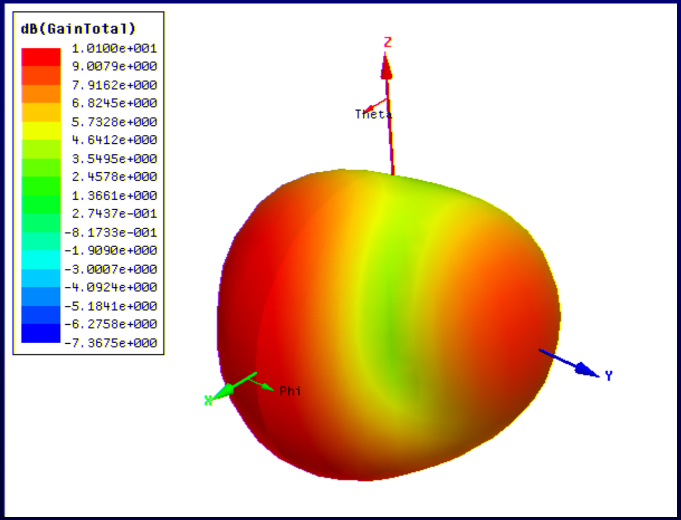
- Advantages
  - Designed specifically for low data rate embedded networks – new generation of radio technology
  - Very low power
  - Many low cost chipsets available:
    - Texas Instruments/Chipcon
    - Atmel
    - ST MicroElectronics
    - FreeScale
    - Ember
    - Nordics, etc.
  - Support for reader mesh through ZigBee.
  - 27 channels available in 3 different frequency bands – 868.3 (1), 906-926 (10) and 2405-2480(16) MHz
  - Integrated, high-security 128-bit AES Encryption
  - Ratified and active standard
  - Short wavelength (λ=12 cm at 2.4 GHz) – good for indoor use

IEEE 802.15.4 Tags

- Operating modes:
  - Tag talk first – optimize battery life
  - Reader talk first – optimize tag density
- Disadvantages of 2.4 GHz 802.15.4
  - Frequency bands are crowded (RFID readers, microwave ovens, cordless phones, Bluetooth (802.15.1), WLAN)
  - Fragmented standards for Network Layer protocols

2.4 GHz vs 433 MHz





Advantages of 433 MHz:

- **Better outdoor propagation**
- **World-wide acceptance**

<u>Advantages of 2.4 GHz:</u>

- **Better indoor propagation**
- **8X smaller antennas**
- **Wide selection of reader antennas**
- **Worldwide acceptance**
- **Higher bandwidth → more data**
- **Integration with other sensor networking standards (Zigbee, mesh)**

➔ 2.4 GHz is usually better choice

Wi-Fi Tags 802.11 (WLAN)

AeroScout Enterprise Visibility Solutions

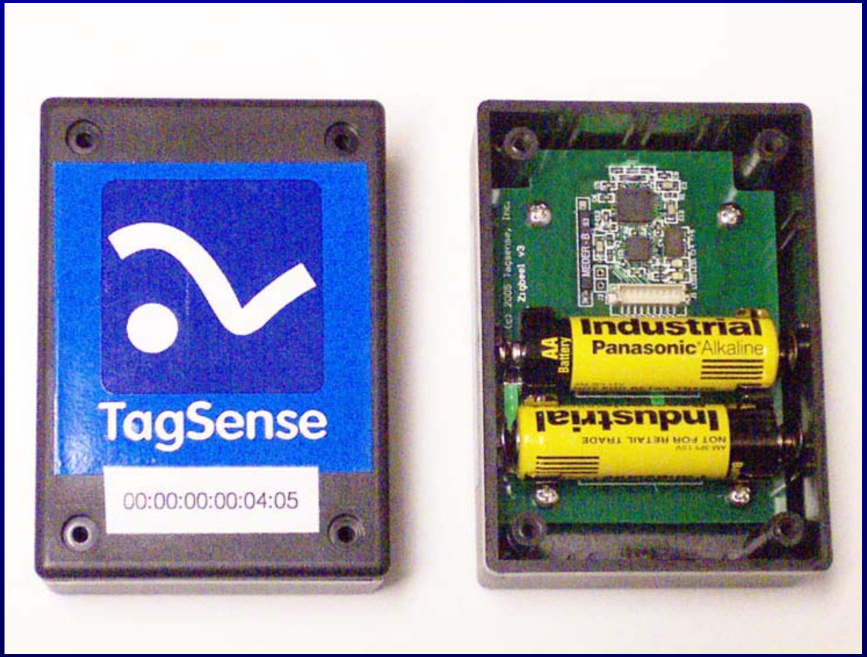
innerwireless

WhereNet A Zebra Technologies Company

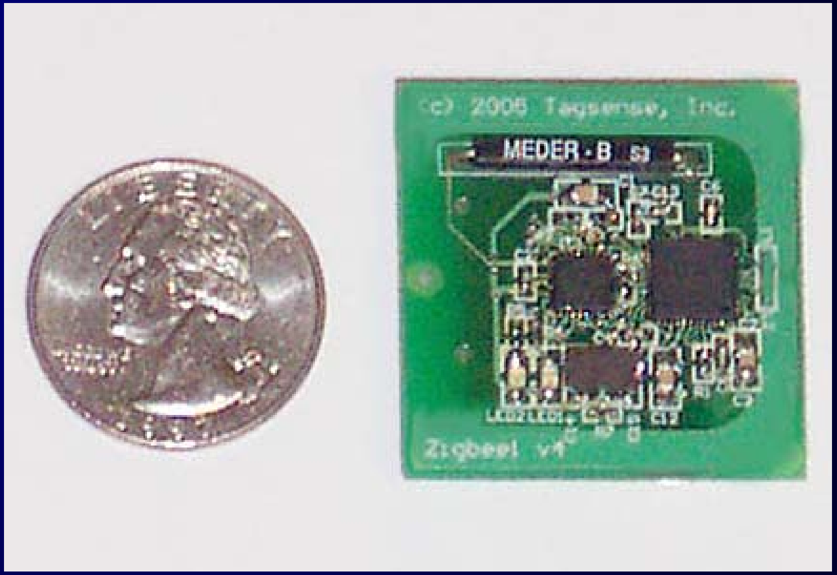
ekahau

Chip vendors: G2, Gain span, ...

IEEE 802.15.4 Tags



ZT-100



ZT-10, ZT-50

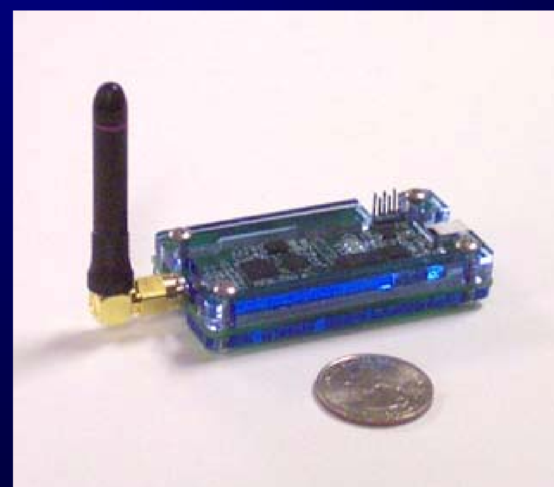
- **802.15.4 –based protocol**
- **Integrated antenna**
- **4-8 sensor inputs**
- **Real-time Clock, Data logging**

Readers

ZR-PCMCIA

ZR-HUB

- Linux-OS 266 MHz Geode processor
- Open Software API
- Wi-Fi + Ethernet interface

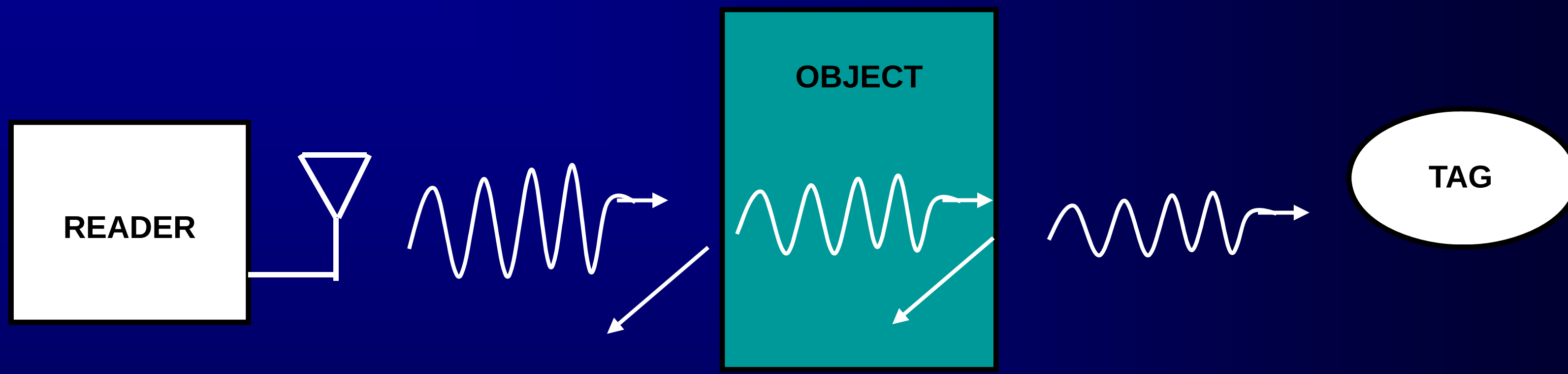


ZR-USB

ZR-SD

RF Propagation Issues

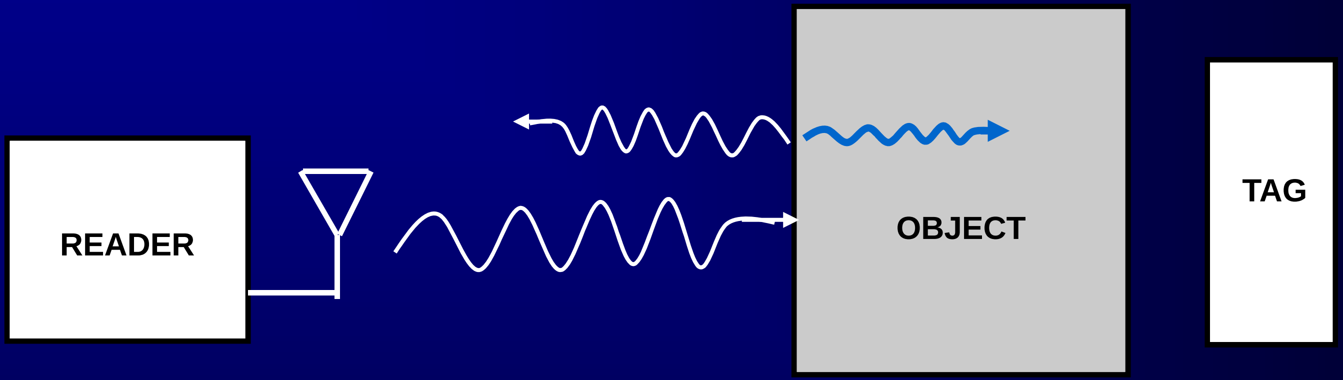
General Loss Mechanisms



Total Path Loss = Reflection Loss + Propagation Loss + Spreading Loss

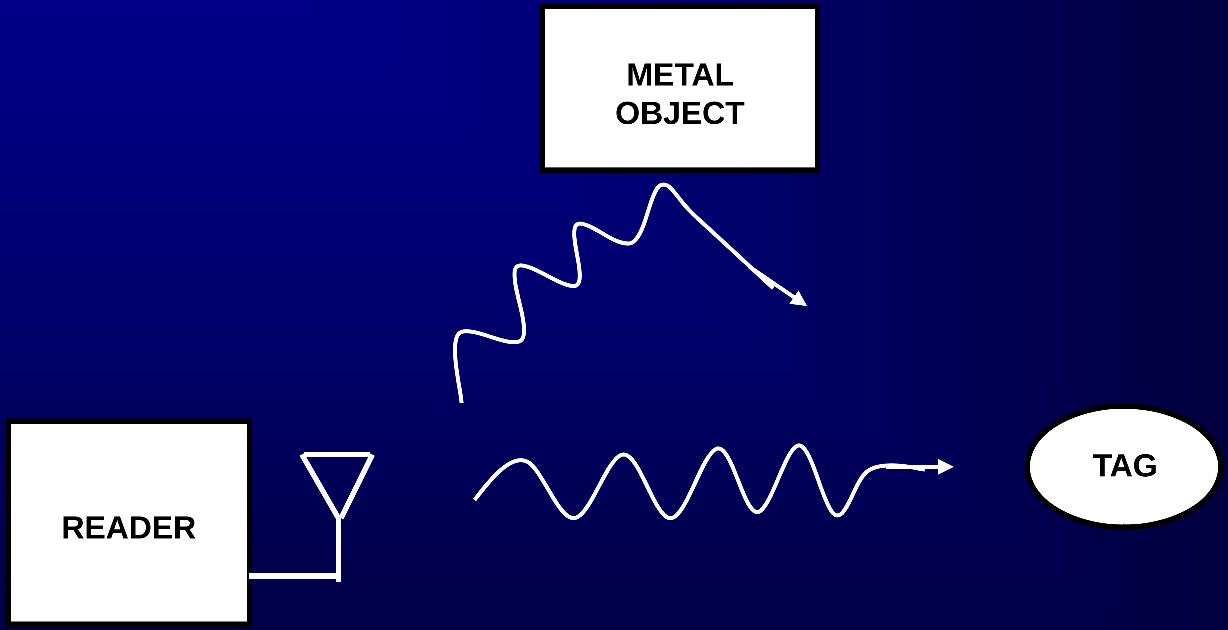
(1/●r^2)

Reflections



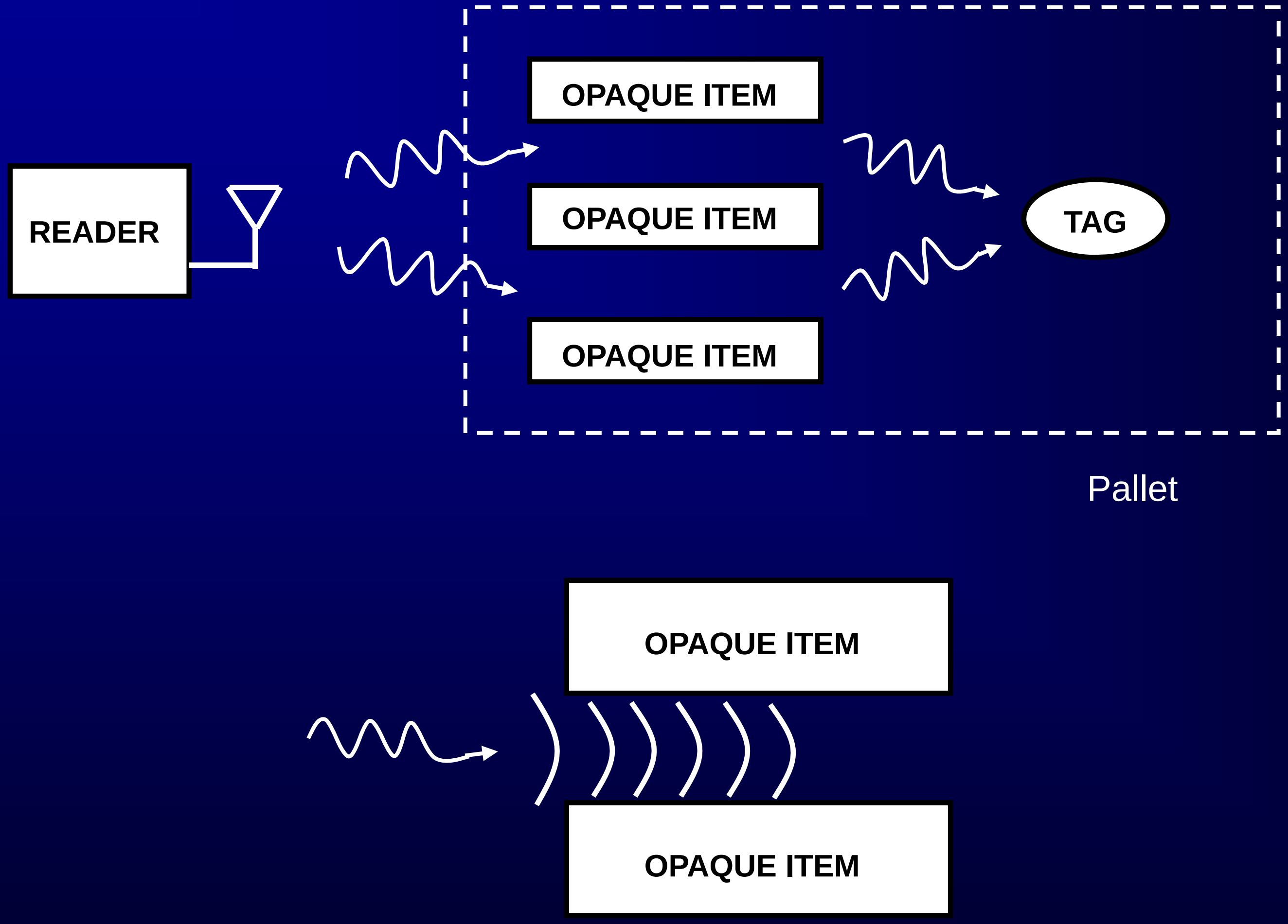
While absorption/loss depends on ε”, reflection depends largely on ε’

Multi-path Reflections



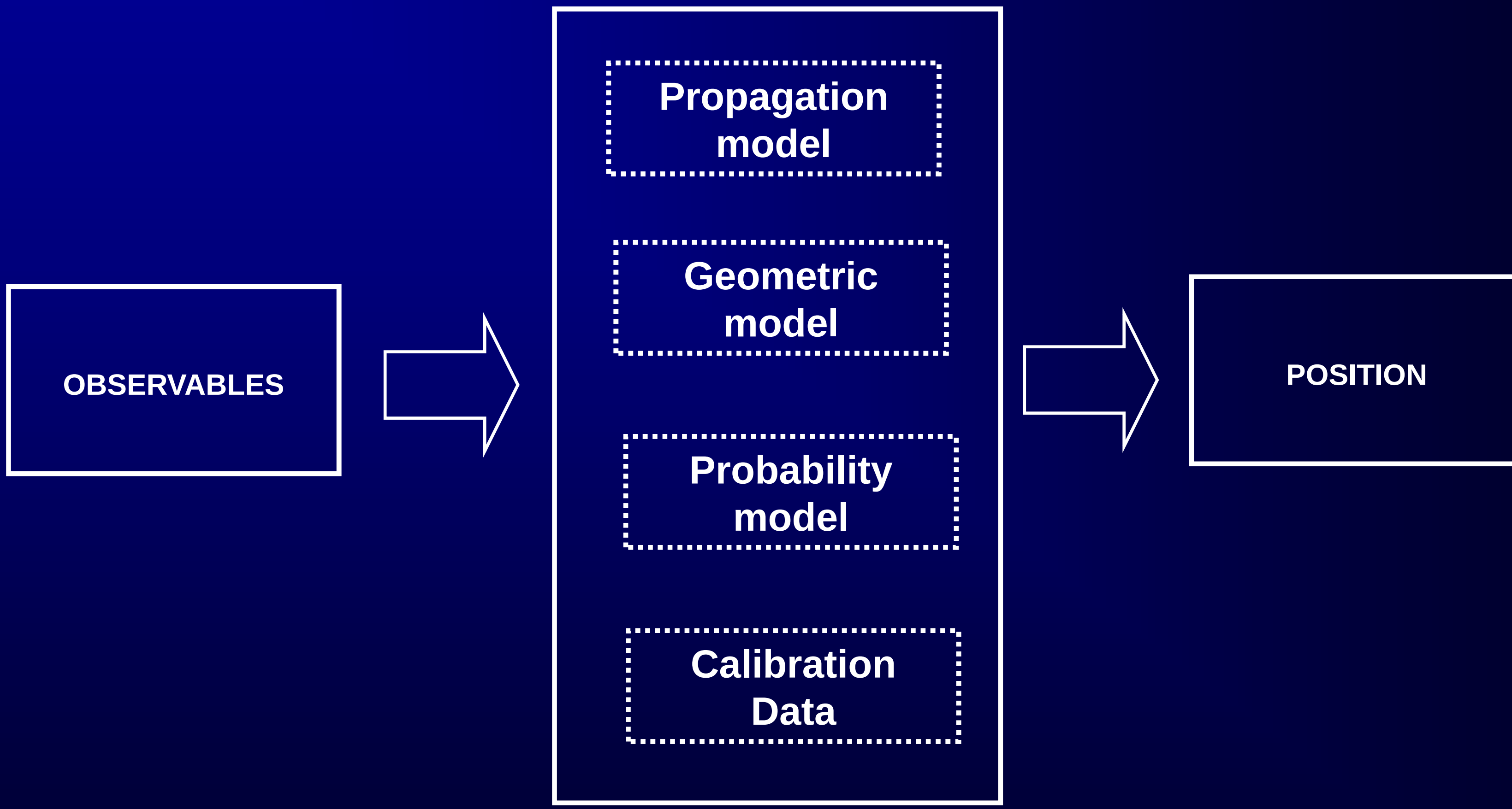
Leads to non-monotonic dependence of RSSI on position

Interference/Diffraction



Emerging Approaches for Improving RTLS

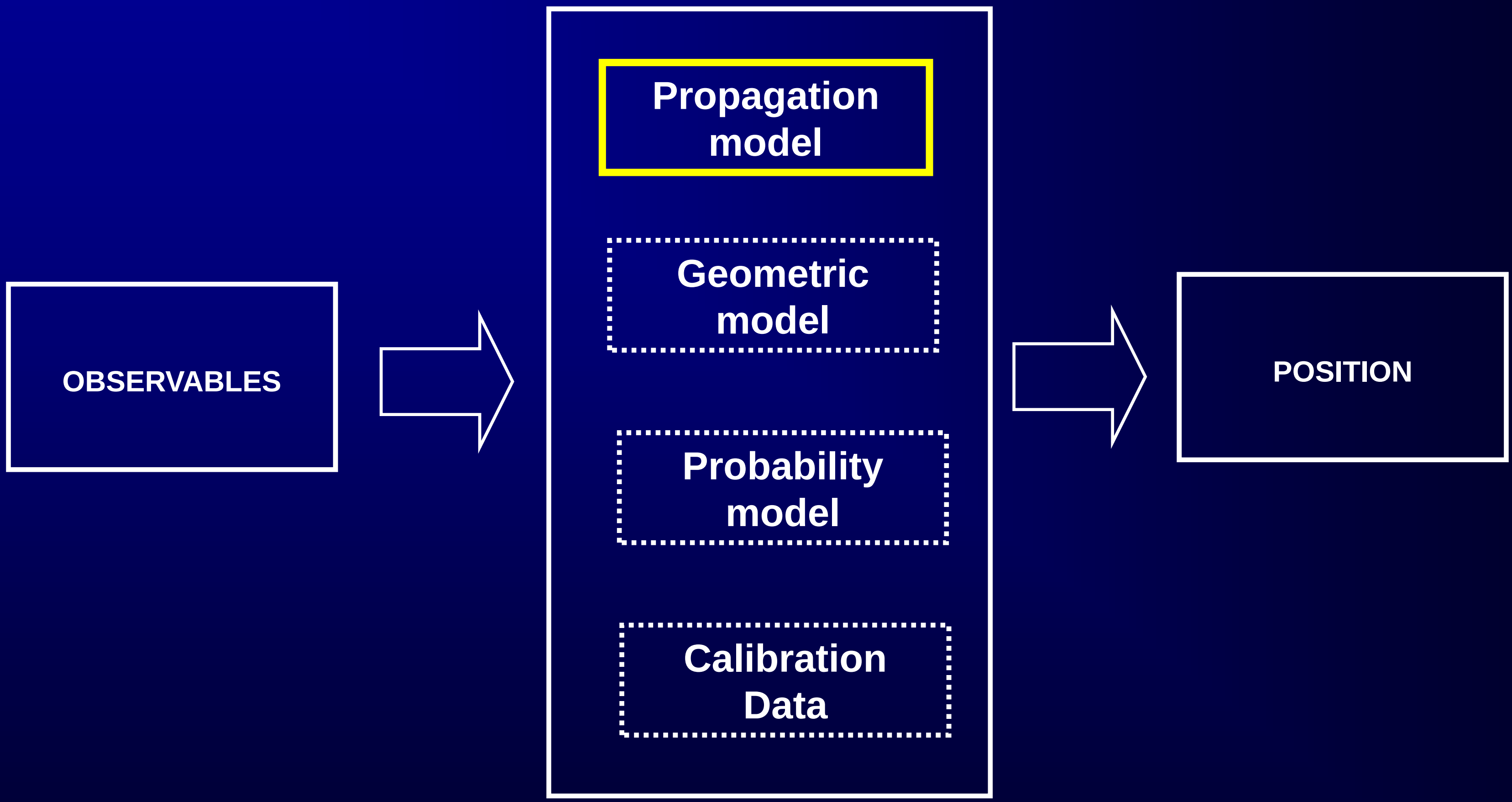
General RTLS Approach



RTLS Model

Better
RF Modelling

General RTLS Approach



RTLS Model

Maxwell's Equations

$$\nabla \times E = -\mu \frac{\partial H}{\partial t}$$

$$\nabla \times H = (J_i + \sigma E) + \varepsilon \frac{\partial E}{\partial t}$$

$$\nabla \cdot E = \frac{q}{\varepsilon}$$

$$\nabla \cdot \mu H = 0$$

Wave Equation Form

Using vector identity:

$$\nabla \times \nabla \times \vec{v} = \nabla(\nabla \cdot \vec{v}) - \nabla^2 \vec{v}$$

Leads to Wave Equation form of Maxwell's Equations:

$$\nabla^2 E = \mu\sigma \frac{\partial E}{\partial t} - \mu\varepsilon \frac{\partial^2 E}{\partial t}$$

$$\nabla^2 H = \mu\sigma \frac{\partial H}{\partial t} - \mu\varepsilon \frac{\partial^2 H}{\partial t}$$

Waves in lossy matter

If we assume time-harmonic fields:

$$E, H \propto e^{j\left(\vec{k}\cdot\vec{r} - \omega t\right)}$$

$$jk \equiv \gamma = \alpha + j\beta$$

Then wave equation can be easily written as:

$$\nabla^2 E = j\omega\mu\sigma E - \omega^2 \mu\varepsilon E$$

$$\nabla^2 H = j\omega\mu\sigma H - \omega^2 \mu\varepsilon H$$

Non-zero but finite conductivity, σ, and dielectric loss

AC Loss

Inside materials:

$$\varepsilon = \varepsilon' - j\varepsilon''$$

$$\tan\delta \equiv \frac{\varepsilon''}{\varepsilon'} = \frac{\sigma}{\omega\varepsilon'}$$

$$J = \sigma E + j\omega\varepsilon' E$$

$$\Rightarrow \quad J = j\omega\varepsilon'(1 - j\tan\delta)E$$

Good conductors:

$$\sigma / \omega\varepsilon' >> 1$$

$$J \approx \sigma E$$

Good dielectrics:

$$\sigma / \omega\varepsilon' << 1$$

$$J \approx j\omega\varepsilon' E$$

Shielding Effects, Reflection

$$\oint \frac{J}{\sigma} \bullet ds = -\frac{d}{dt} \iint_S \mu H_a \bullet da$$

$$\oint H_{op} \bullet ds = \iint_S J \bullet da$$

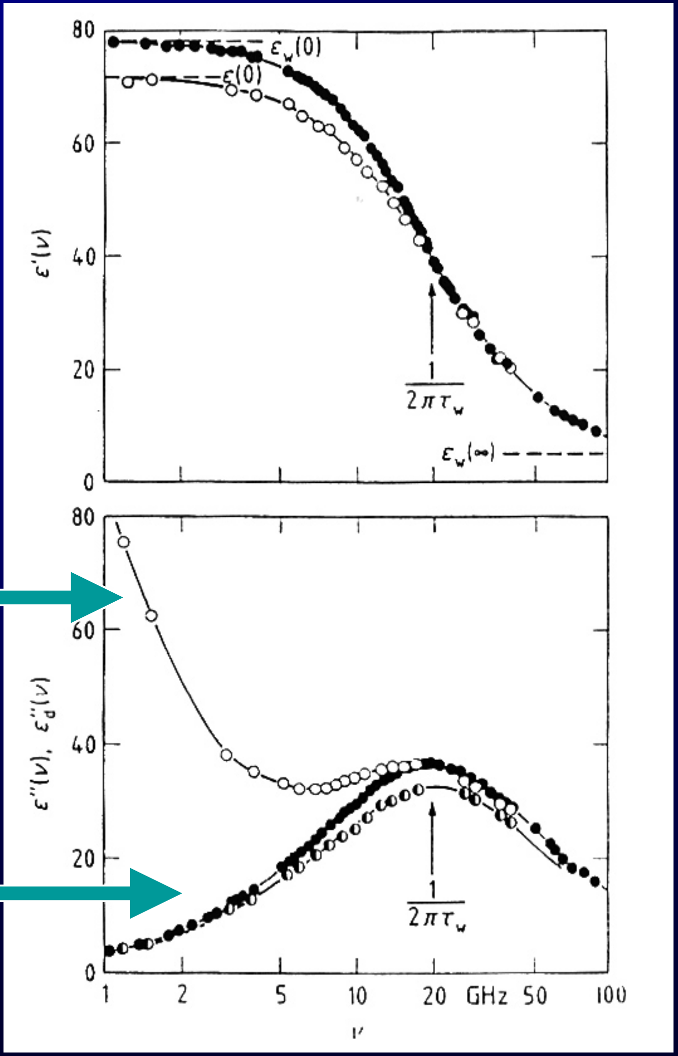
$$\tau_m = \mu \sigma l_1 l_2$$

Materials properties

RF Loss critically depends on composition

Salt added (.05M)

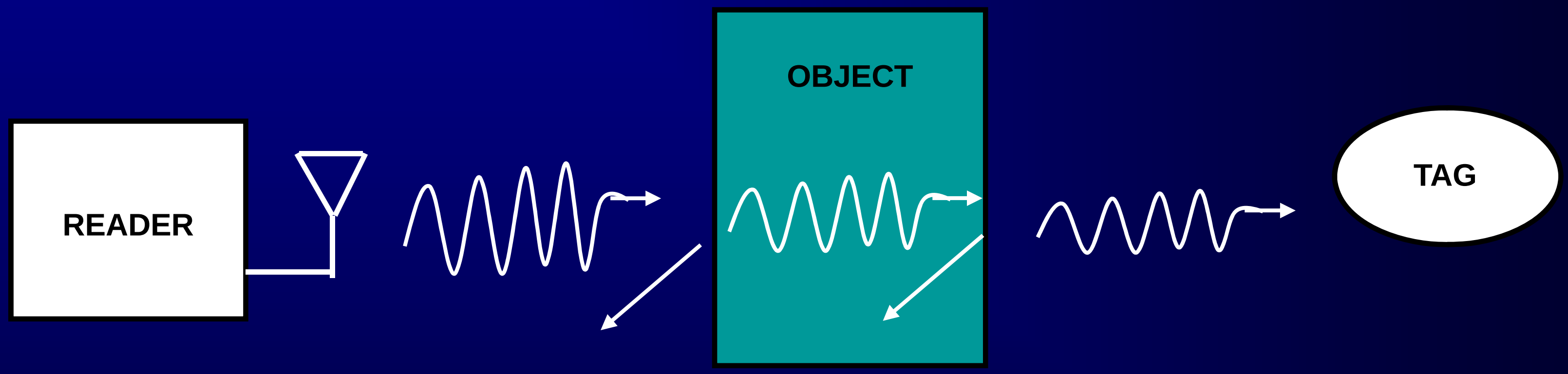
No salt



ε'

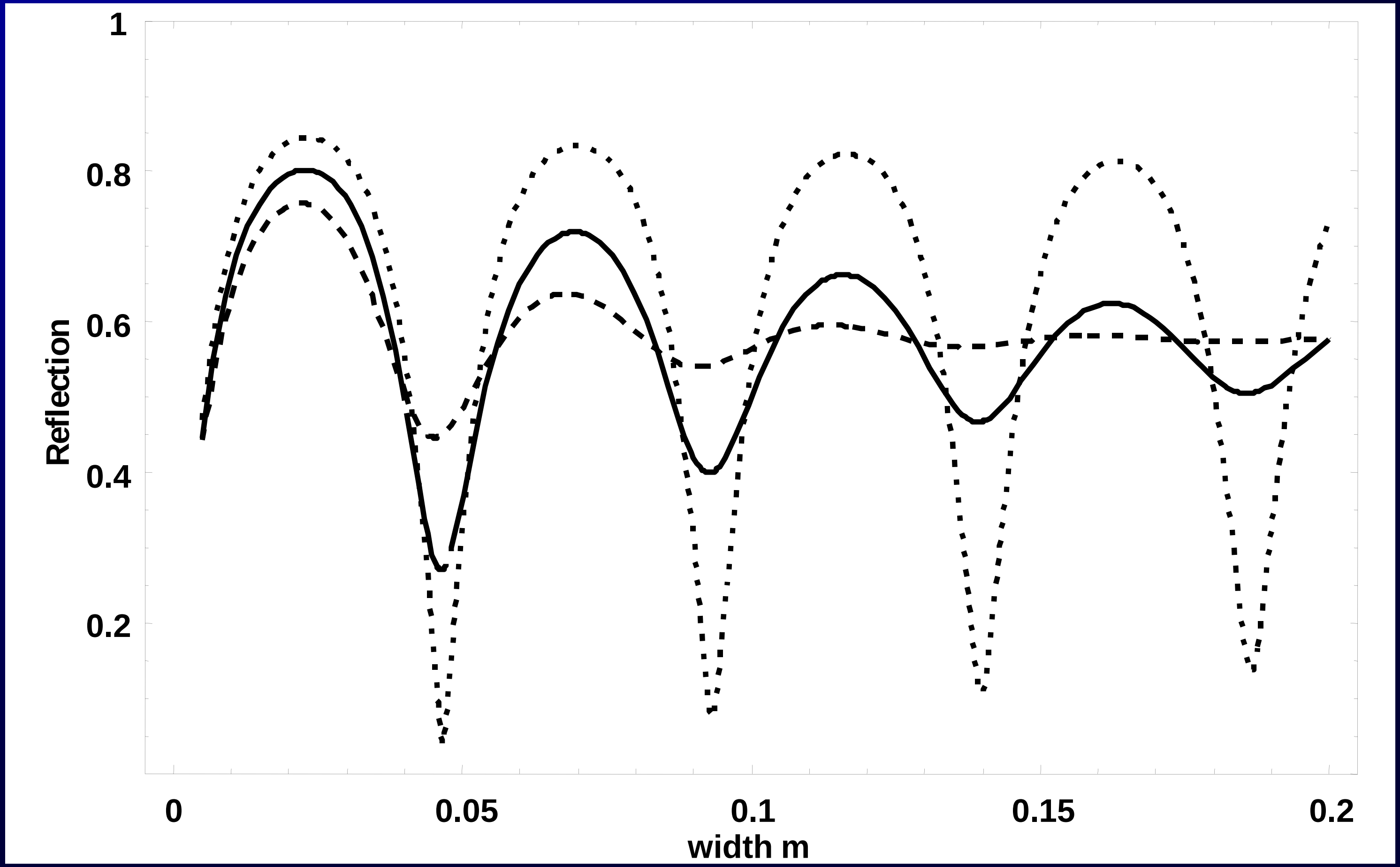
tanδ

Reflection - Transmission



Reflection 1 Reflection 2

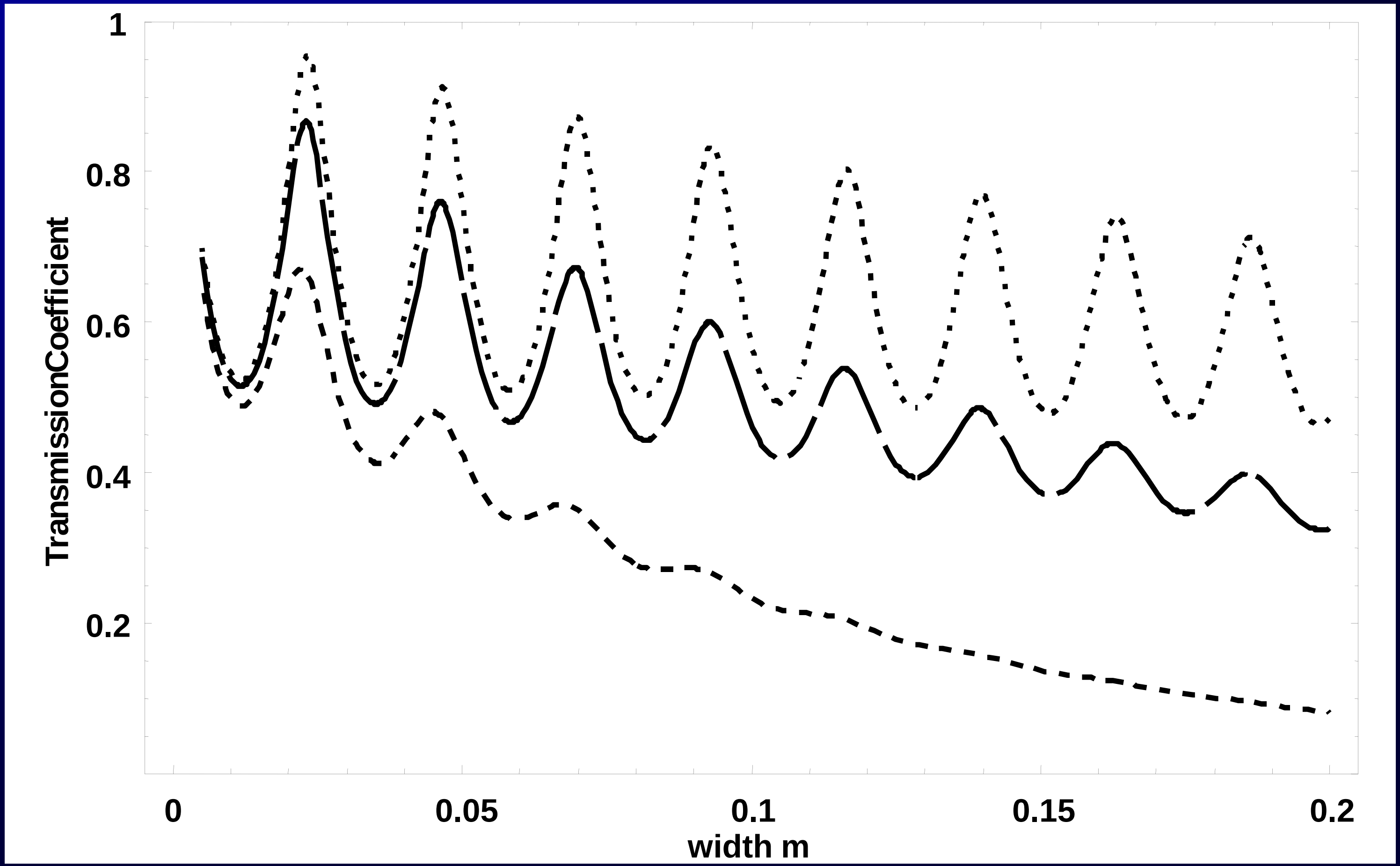
Simulation: Reflection



e’ = 12.75

♦ = 0.01, 0.03, 0.1

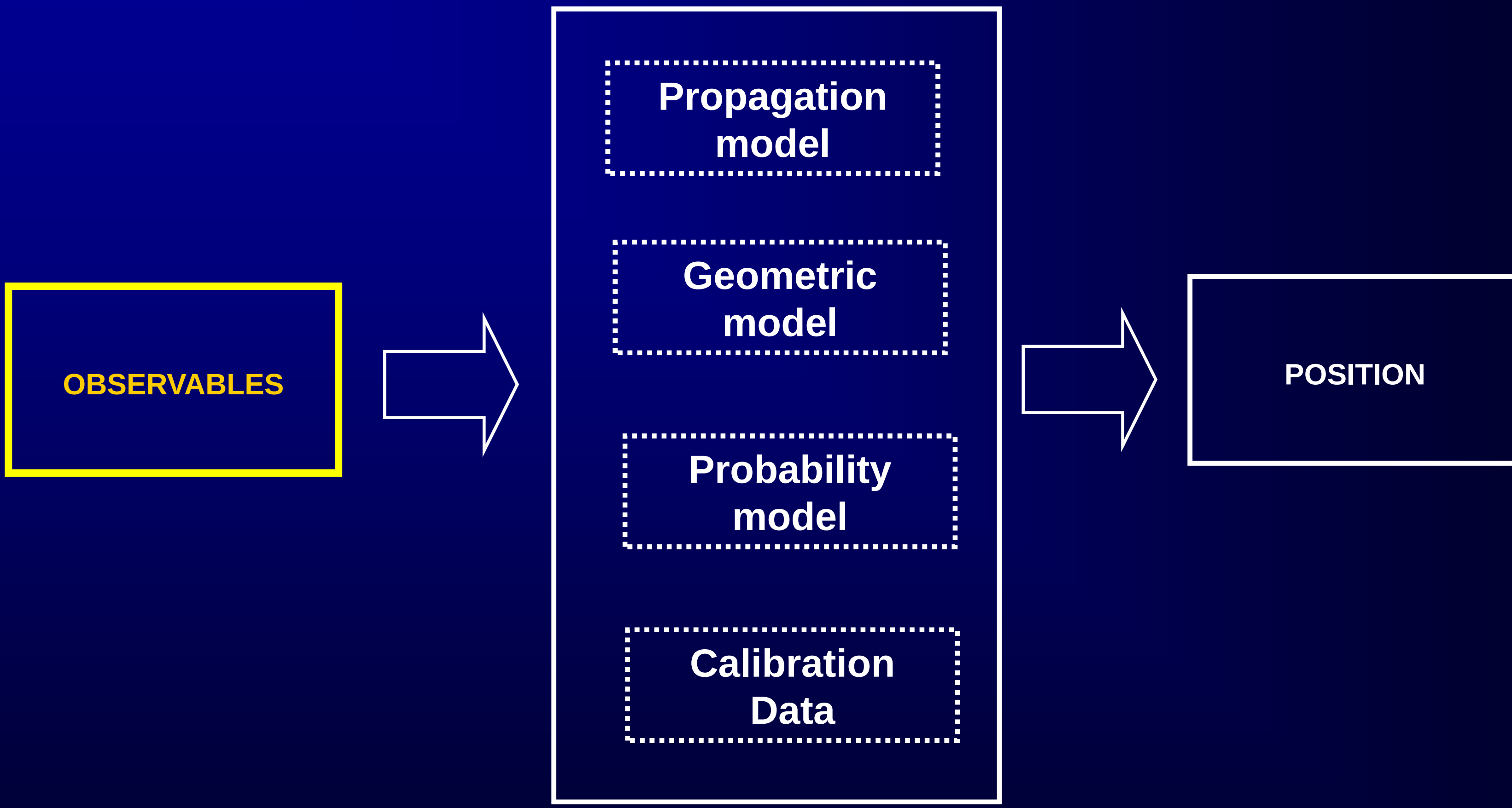
Simulation: Transmission



e’ = 12.75 ♦ = 0.01, 0.03, 0.1

Better
RF Signalling

General RTLS Approach



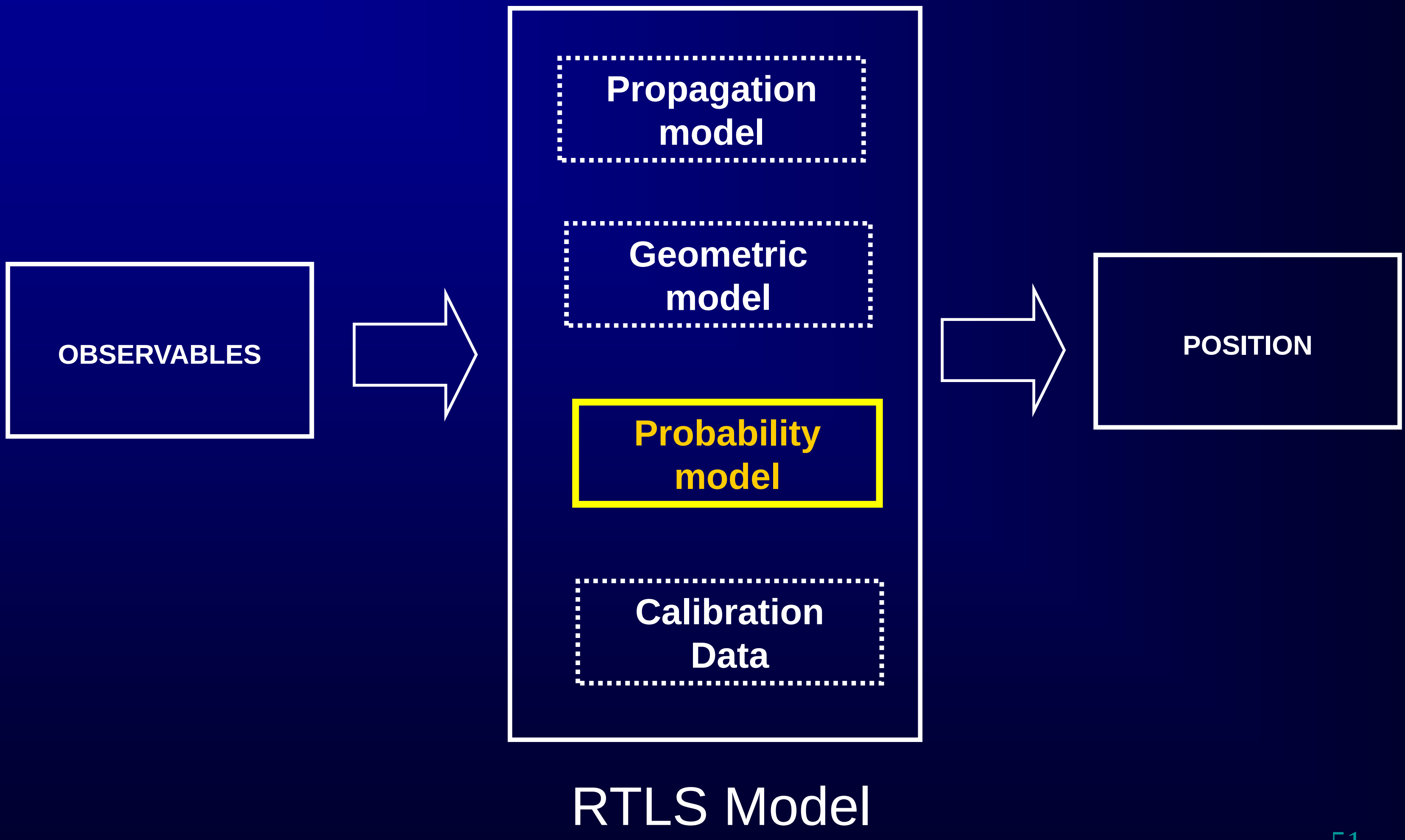
RTLS Model

More Observables

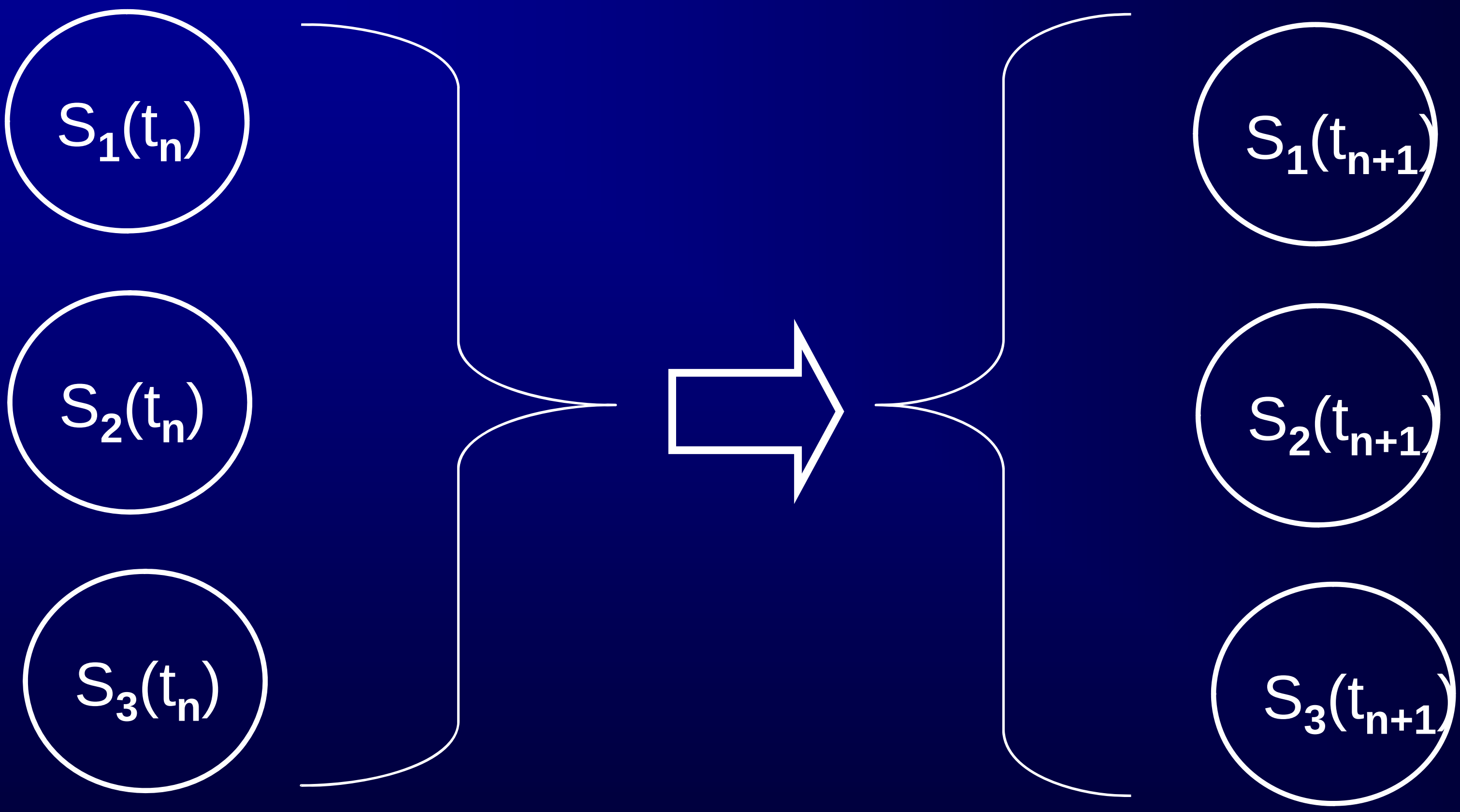
- CMOS RFICs are continuously improving and adding more integrated functionality
- Using standard CMOS RFICs, can we generate more observables?
- Examples: power modulation, phase jitter, etc.

Better
Probability Models

General RTLS Approach

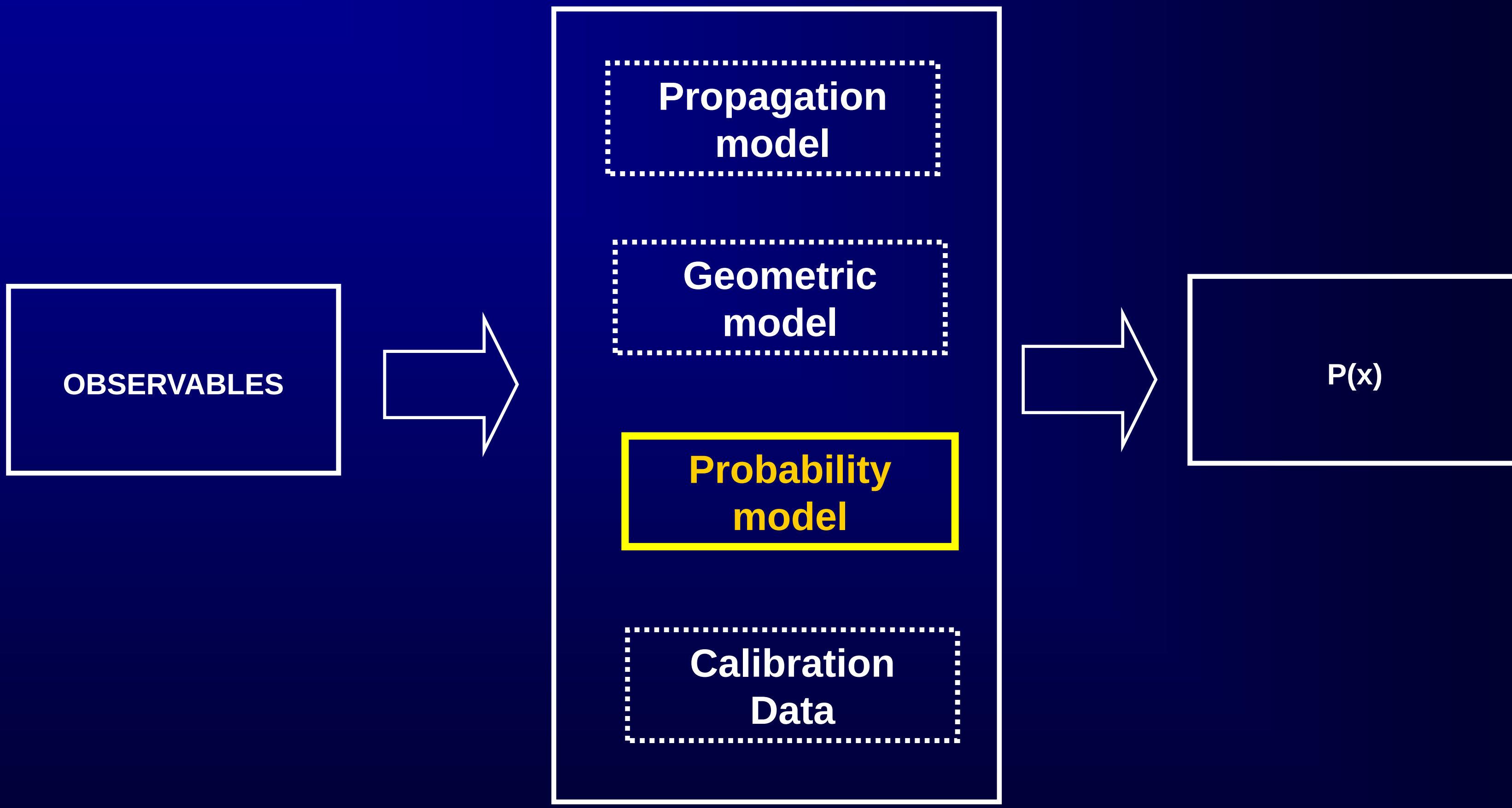


Machine Learning



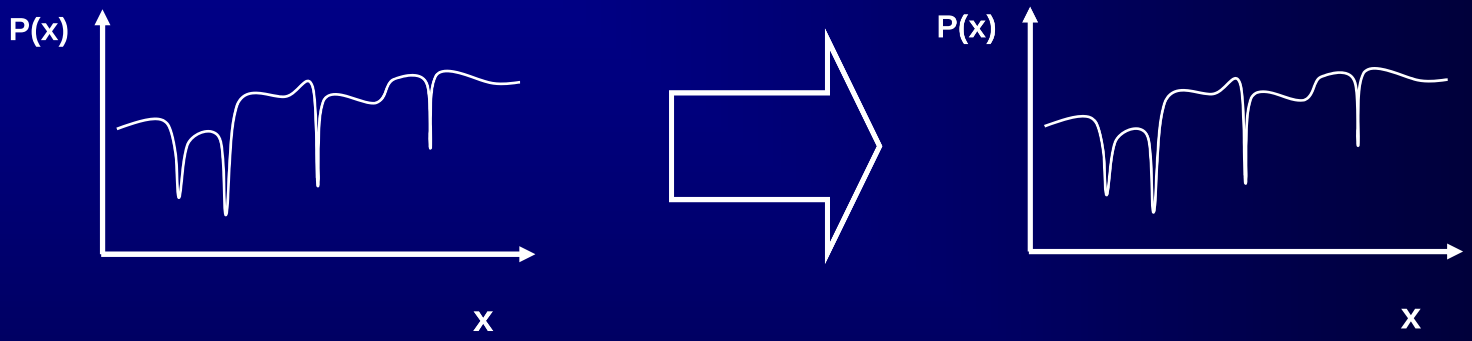
- Hidden Markov Models (HMM)

Generating Probabilities



RTLS Model

Bayesian Propagation



- Propagate the P_0 (prior) to P_1 (posterior)

Probability Summary

- Exploit locality property of Markov model based on recent state
- Use Bayesian process to evolve probability distribution

Summary

Conclusions

- Many RTLS solutions exist for Active RFID
- RF propagation issues still exist – particularly for dynamic environments
- Emerging research:
- RF CMOS ICs are enabling new signalling
- Powerful Machine Learning techniques and cheap fast computers/microntrollers are enabling unprecedented performance for RTLS

Thankyou.

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