Outline

• Where? Who?
• Introduction
• Wireless Sensor Networks
• Real Time Locating Systems
• Research Projects
• Localisation in Wireless Sensor Networks
• Case Study
• State of the Art / future of Localisation
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Where?

Population Belgium: 10.8 million, Antwerp: 461,000
Who?

• University College of Antwerp
  • Dept. of Applied Engineering & Technology:
    • # Students: +/- 1200
  • Degrees: Professional Bachelor, Academic Bachelor & Master
  • Fields:
    • Electronics-ICT engineering
    • Construction engineering
    • Chemical engineering
    • Electromechanical engineering
    • Electronics-ICT
    • Real-estate
    • Graphical and digital media
Who? (are we)

- E-lab research group:
  - 22 staff members
    - 9 full-time researchers & Ph.D. Students
  - Ambient Intelligence (AMBIT)
    - Positioning on the macro, medium, and micro level
    - Auto-identification, and RF communication technologies (RFID, NFC)
    - 3D location tracking and inter-working of embedded localization and communication systems.
  - Ambient Multimedia and Imaging (AMMI)
    - Classification and segmentation problems (image & video processing)
      - Gesture recognition
      - Medical signal processing.
    - segmentation of MR images and the investigation of MR spectroscopy data in order to detect adipose tissue.

http://www.artesis.be/iw/elab/
Who? (are we)

- **Electronics-ICT Group**: 7 staff members
  - Network Security: Malware detection, botnets, network attacks
  - Multimedia Systems: Software development for Natural User Interfaces (NUI)
  - Embedded Systems: microcontroller & FPGA applications
    - ARM Cortex M3, Intel 8051,...
  - Smart Objects: applications for Wireless Sensor Networks
    - Crossbow TelosB, TinyOS, SunSPOT,...

[www.artesis.be/technologie]
Who? (am I)

- Ing. Jeroen Doggen, MSc.
  - Graduated at Artesis University College of Antwerp, 2006
    - Thesis: Simulation of H.264 Video streaming using OPNET Modeler
      - Erasmusstudent Universitat Ramon Llull, Barcelona
- Researcher Artesis Hogeschool Antwerpen (2006-2008)
  - E-lab: Topic: Wireless sensor networks (WSN) ([www.e-lab.be](http://www.e-lab.be))
- Researcher University of Antwerp (2006-2008)
  - Dept. Mathematics & Computer Science ([pats.ua.ac.be](http://pats.ua.ac.be))
    - Performance Analysis of Telecommunication Systems Group (PATS)
    - Topic: Network traffic simulation: WSN, InfiniBand & Fibre Channel networks
- Lecturer electronics-ICT (Artesis), (2008 – Present)
  - Mathematics, digital electronics (logic design)
  - Microcontrollers & embedded systems
  - Computer Architectures
  - Smart Objects & Wireless Sensor Networks
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Wireless Sensor Networks

A wireless sensor network is a set of small autonomous systems, called sensor nodes which cooperate to solve at least one common application. Their tasks include some kind of perception of physical parameters [1].

Autonomous motes can measure their environment, process the data and communicate ...
... to work together towards one or more applications ... which often benefit from location information.

WSN Specifications

• Hardware: CrossBow TelosB
  • TI MSP430 microcontroller with 10kB RAM
  • Ultra low-power
  • IEEE 802.15.4 compliant radio
  • Integrated temperature, light, humidity and voltage sensor
  • Programmable via USB interface
  • Integrated antenna

• Embedded software: TinyOS 2.1
  • Most popular OS for Wireless Sensor Networks
  • Open source
  • Energy efficient – low power
    • Hurry up and go to sleep
    • Split phase programming
  • Multi-platform
WSN Specifications

- **Sensorboard**
  - 3D accelerometer
  - Temperatuur sensor
  - Licht sensor
  - 8 tri-color LEDs
  - 6 analog inputs
  - 2 drukknoppen
  - 5 I/O pins
  - 4 output pins

- **Processorboard**
  - 180 MHz 32 bit ARM920T core
  - 512K RAM/4M Flash
  - integrated antenna
  - USB interface
  - Squawk VM

- **Battery**
  - 3.7V 720maH battery
Senseless WSN Framework: overview

- Distributed system:
  - Common data & command interface to different WSNs
    - Wireless Sensor Network: TelosB, SUNspots (TinyOS, Squawk VM)
    - Databases: MySQL, DB2 (ODBC)
    - GUIs: PHP, .NET, C#, AJAX, XML over TCP, WCF
    - Controller: JAVA & C# .NET 3.5
Senseless WSN Framework: architecture

- This is the direction of how the connection is started. (Replies can occur in opposite direction)
- Connection over TCP/IP in sql
- Connection over TCP/IP using sockets and in XML

Diagram showing the architecture of the Senseless WSN Framework with components such as MySQL, DB2, Sunspot, TelosB, and Web GUI and Desktop GUI.
Senseless WSN Framework

Summary

All the sensor values of the nodes placed on the map selected below will be shown in a table. By selecting the option 'ok' all sensors will be shown.

Choose a map: plan.jpg (66 KB) Set map

<table>
<thead>
<tr>
<th>Nodeid</th>
<th>Type</th>
<th>Date</th>
<th>Temp(K)</th>
<th>Light</th>
<th>Humidity</th>
<th>Power(%)</th>
<th>Accel x;y;z</th>
<th>Tilt x;y;z</th>
<th>Leds</th>
<th>Buttons</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>TelosB</td>
<td>01-01-70 01:00</td>
<td>305.2</td>
<td>50</td>
<td>NA</td>
<td>60</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>SunSPOT</td>
<td>01-01-70 01:00</td>
<td>305.2</td>
<td>50</td>
<td>1144</td>
<td>60</td>
<td>1 ; 1.5 ; -1</td>
<td>11 ; 3 ; 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>SunSPOT</td>
<td>01-01-70 01:00</td>
<td>400</td>
<td>100</td>
<td>200</td>
<td>60</td>
<td>1 ; 1.5 ; -1</td>
<td>11 ; 3 ; 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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Definition:
Real Time Locating Systems (RTLS) are automated systems that continually monitor the location of assets and personnel.
RTLS – Definitions & Goal

• **Anchor Nodes:**
  - Nodes that know their coordinates a priori
  - By use of GPS or manual placement
  - For 2D three and for 3D minimum four anchor nodes are needed

• **Blind Nodes**
  - Nodes with an unknown location
  - The node can have any hardware: Wifi, WSN, GPS, MEMS, ...

• **Goal:**
  - To position a blind node by using pair-wise measurements with the anchor nodes.
  - For example:
    - Determine the distances between blind nodes and anchor nodes.
    - Derive the position of each node from its anchor distances.
RTLS System – System Properties

• Absolute vs relative reference of location information
  • Absolute reference
    • Eg: GPS
  • Relative reference
    • Use triangulation to calculate absolute reference

• Localised vs centralised computing
  • Localised computing
    • Eg: GPS
    • Solves privacy issues
  • Centralised computing
    • In most commercial Wi-Fi positioning systems
    • Tag sends info to server
  • Combination possible
    • Eg: Wi-Fi-Assisted-GPS [2]

RTLS System – System Architecture
RTLS Systems - Positioning Techniques

- Triangulation
  - determining the intersection of distances measured from multiple known reference points
- Lateration
  - Time-Of-flight
  - Time of Arrival
  - Time Difference of Arrival
  - Round Trip Time
  - Attenuation
- Proximity
- Scene Analysis
RTLS Systems – Proximity

- Detecting physical contact
  - Pressure sensors, touch sensors, capacitive fields, ...
- Monitoring wireless cellular access points
  - Is tag in range of access point?
  - A: ideal RF environment
  - B: more realistic
  - C: in room (Ultrasound, infra-red,..)
- Observing automatic ID systems
  - Credit card terminals, computer logins,
  - RFD cards access terminals, ...
RTLS Systems – Scene Analysis

- **Image analysis**
  - Camera observes a scene
  - Simplified scene is used to recognise and compare features
- **Static image analysis:**
  - Observer images are looked up in a predefined data-set to map them to the objects location
    - e.g. traffic camera's

(a) ![Image](image1.png)

(b) ![Image](image2.png)
Positioning Techniques – Scene Analysis

Fingerprinting

• Use pattern of RF signals as image
• WLAN Fingerprinting, use RSS of access points
• RADAR system[1]

• 2 steps
  • Offline phase
  • Real-time phase

Positioning Techniques – RSSI Problems

RTLS Technologies

- RFID
- Wi-Fi-based positioning
- GNSS (e.g. GPS)
- GSM
- UWB (e.g. Essensium 'Lost' Technology)
- Sensor Network
- Infrared
- Ultrasound
- Computer Vision
- RADAR
- ...

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SCALA Project

- System Convergence in Applications of Location Awareness
- Wijngaard Natie
  - Terminal: ships metal bulk & project goods, packaging, stocking
  - Revenue 6,457,629 € (2008)
### SCALA Project

#### Area

<table>
<thead>
<tr>
<th>Area</th>
<th>Absolute (m²)</th>
<th>Relative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor</td>
<td>32,500</td>
<td>16</td>
</tr>
<tr>
<td>Outdoor</td>
<td>170,000</td>
<td>84</td>
</tr>
<tr>
<td>Total</td>
<td>202,500</td>
<td>100</td>
</tr>
</tbody>
</table>
Initial Vision

- Wi-Fi
- GSM
- Wi-Fi
- GPS
- Wi-Fi
- GSM
- Wi-Fi
- GPS

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Wifi Deployment
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LocON: Seamless Indoor and Outdoor Localisation

• FP7 Project – Funded by the European Union
  • Total cost: 3,8 Mio Euro

• Goals: Generate new monitoring and control services integrating context awareness for safety and security applications (in large scale infrastructures)
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RSS Based Localisation in WSNs

- Received signal strength based ranging (RSS)
  - RSS attenuates with distance due to free-space losses
  - Log-normal-shadowing model: [5]
    \[
    PL = P_{Tx_{dBm}} - P_{Rx_{dBm}} = PL_0 + 10\gamma \log_{10}\frac{d}{d_0} + X_g,
    \]
  - Translate RSS measurements to distances
    - PL: Total path loss measured (dB)
    - PTx: Transmitted power [dBm]
    - PRx: Received Signal Strength [dBm]
    - PLo: Path loss in dB at a distance of d0 (reference distance)
    - \(\gamma\): Path loss exponent (distance power gradient)
    - Xg: Gaussian random variable: shadowing, fading, multipath

- Unknown coordinate estimation:
  - 2-D Euclidean distance (based on Pythagoras' theorem)
    \[
    \sqrt{(x - x_i)^2 + (y - y_i)^2} = d_i, \quad 1 \leq i \leq n
    \]

RSS Based Localisation in WSNs

- Measure path loss for a reference distance: 1m
- Calibration phase: estimating $\gamma$ (Path loss exponent)
  - Adapt the propagation model for the local environment
  - Empirical coefficient values for indoor propagation [6]

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Frequency of Transmission</th>
<th>$\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum, infinite space</td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>Retail store</td>
<td>914 MHz</td>
<td>2.2</td>
</tr>
<tr>
<td>Grocery store</td>
<td>914 MHz</td>
<td>1.8</td>
</tr>
<tr>
<td>Office with hard partition</td>
<td>1.5 GHz</td>
<td>3.0</td>
</tr>
<tr>
<td>Office with soft partition</td>
<td>900 MHz</td>
<td>2.4</td>
</tr>
<tr>
<td>Office with soft partition</td>
<td>1.9 GHz</td>
<td>2.6</td>
</tr>
<tr>
<td>Textile or chemical</td>
<td>1.3 GHz</td>
<td>2.0</td>
</tr>
<tr>
<td>Textile or chemical</td>
<td>4 GHz</td>
<td>2.1</td>
</tr>
</tbody>
</table>

\[
PL = P_{Tx_{dBm}} - P_{Rx_{dBm}} = PL_0 + 10\gamma \log_{10}\frac{d}{d_0} + X_g,
\]

RSS Based Localisation in WSNs

- RSS based ranging has several advantages
  - Low-cost & low complexity
    - Most WSN radios support RSSI measurements out of the box (e.g. CC2420 [7])
- RSS based ranging has several drawbacks
  - Environmental errors
    - Rapid time varying
      - Movement of nodes, objects and people
      - Noise, interference
    - Static environment dependent
      - Layout of the environment: e.g. placement of doors
      - Multipath, shadowing
  - Device errors
    - Inter-device differences
    - Depleting batteries
    - Antenna orientation
    - Receiver/transmitter variability

[7] TI CC2420: a single-chip 2.4 GHz IEEE 802.15.4 compliant RF transceiver
RSS Based Localisation Algorithms in WSNs

- Localisation Requirements:
  - RSS based ranging 'piggybacks' on the existing network
    - No extra hardware needed
  - Channel should be modeled accurately
    - Difficult on nodes with limited energy and processing power
  - Distributed and self-organising
    - No central dependency
    - Individual nodes and links between nodes are prone to failure
  - Energy usage
    - Processing and communication should be minimised
  - Adaptive
    - Number of Anchor nodes and network density is variable
  - Responsiveness
    - Mobile nodes are possible
RSS Based Localisation Algorithms in WSNs

Localization schemes

Coordinate-free

Coordinate-based

Range-free

Anchor-based

Hop-based

Triangulation

Range-based

Propagation time (ToA)

Time readings (TDoA)

Angle readings (AoA)

Signal strength (RSSI)

RSS Based Localisation Algorithms in WSNs

• Coordinate-free
  • Based on geographic clustering techniques [9]
  • Only possible in very dense networks

Range Free Localisation: Coordinate based

- **Range-based**
  - Explicit distance measurement
  - e.g. RSSI, AoA, TDOA, ToA
- **Range-free**
  - Implicit distance measurement
    - Anchor & hop based, ring overlapping, triangulation [10]

Range Free Localisation: Hop based

- DV-Hop algorithm (Topology: several AN's, many BN's)
  1. AN position Flooding: AN & BN record their hop-distance to (other) AN in the network.
  2. Hop Correction Estimation / Flooding: AN estimate the average length for one hop (hop correction) and than broadcast this information to their neighbors.
  3. Position estimation. Nodes estimate their position according to the number of hops recorded for each known Source and to the hop correction.
Range Free Localisation: CL

- Range-free: anchor based
  - **Centroid Localisation**: Coarse grained localization
    - Calculate the unknown position as the centroid of the anchor nodes within their communication range

Location:

\[
(x'_i, y'_i) = \frac{1}{n} \sum_{j=1}^{n} (x_j, y_j)
\]

Localisation error:

\[
f_i = \sqrt{(x'_i - x_i)^2 + (y'_i - y_i)^2}
\]
**Weighted** Centroid Localisation

- A weight is coupled to the position of each anchor node by its RSS
  - Shorter distances cause higher weights
  - Weight inversely proportional to distance
    - \( h \): degree \(\rightarrow\) tuning of the system

\[
\begin{align*}
  w_{ij} &= \frac{1}{(d_{ij})^h} \\
  (x''_i, y''_i) &= \frac{\sum_{j=1}^{n} w_{ij} \cdot (x_j, y_j)}{\sum_{i=1}^{n} w_{ij}}
\end{align*}
\]
Range Free Localisation: WCL

- **Weighted Centroid Localisation**
  - Friis free space transmission equation:
    \[
    P_{rx} = P_{tx} \cdot G_{tx} \cdot G_{rx} \cdot \left( \frac{\lambda}{4\pi d_{ij}} \right)^2
    \]
    
    \(P_{tx} = \) Transmission power of sender
    \(P_{rx} = \) Remaining power of wave at receiver
    \(G_{tx}, G_{rx} = \) Gain of transmitter and receiver
    \(\lambda = \) Wave length
    \(d_{ij} = \) Distance between sender and receiver
    
    \[P'_{rx} = P_{ref} \cdot 10^{\frac{RSSI}{20}} \quad \iff \quad RSSI = 20 \cdot \log_{10} \frac{P'_{rx}}{P_{ref}}\]
    
    \[w_{ij} = \left( P'_{rx} \right)^g\]
    
    \[w_{ij} = \left( P_{ref} \cdot 10^{\frac{RSSI}{20}} \right)^g\]
Range Free Localisation: SDWCL

- **Static Degree** Weighted Centroid Localisation
  - The degree 'g' has to be chosen / calculated / tested?
    - Optimal Static degree can be defined using simulation

\[ w_{ij} = \left( P'_{rx} \right)^g \]
Range Free Localisation: DDWCL

- **Dynamic Degree** Weighted Centroid Localisation
  - Subregion determination

\[
\begin{align*}
\omega_{ij} &= (P'_{rx})^g
\end{align*}
\]

<table>
<thead>
<tr>
<th>RSSI constraints</th>
<th>Relevant subregion</th>
</tr>
</thead>
<tbody>
<tr>
<td>((RSSI(AP_1) &gt; RSSI(AP_4)) \land (RSSI(AP_3) &gt; RSSI(AP_2)))</td>
<td>(C_{1,1})</td>
</tr>
<tr>
<td>((RSSI(AP_4) &gt; RSSI(AP_1)) \land (RSSI(AP_2) &gt; RSSI(AP_3)))</td>
<td>(C_{1,2})</td>
</tr>
<tr>
<td>((RSSI(AP_1) &gt; RSSI(AP_4)) \land (RSSI(AP_2) &gt; RSSI(AP_3)))</td>
<td>(C_{2,1})</td>
</tr>
<tr>
<td>((RSSI(AP_4) &gt; RSSI(AP_1)) \land (RSSI(AP_3) &gt; RSSI(AP_2)))</td>
<td>(C_{2,2})</td>
</tr>
</tbody>
</table>

\[
\Rightarrow Q_1 = \frac{x_1}{y_1}
\]

\[
\Rightarrow Q_2 = \frac{x_2}{y_2}
\]
Range Free Localisation: DDWCL & SDWCL

- **Dynamic Degree** Weighted Centroid Localisation
  - Test results [5]

$$w_{ij} = (P'_{rx})^g$$

Test setup:
- Test 1: $l_1 = 5.8$ m, $l_2 = 3.2$ m
  - $p = 1.81$
- Test 2: $l_1 = 4.8$ m, $l_2 = 4.8$ m
  - $p = 1.0$

Optimal values for $g$
- DWCL
- SWCL ($g=0.93$ @ $p=1$; $g=0.78$ @ $p=1.81$)

Range Free Localisation: ROCRSSI

- **Ring Overlapping based on Comparison of RSSI**. [8]
  - Circles around A & B:
    - $d(s,A) > d(A,B)$
    - $d(s,A) < d(A,C)$
  - Circle around C:
    - $d(s,C) < d(B,A)$
  - Resulting possible position: grey area

- **Grid-scan algorithm**
  - Terrain in converted to a grid
  - Each point is initialized at zero
  - Each time a point fall in to a grid → +
- **Not based on absolute RSS values**
- **Should be robust**
  - handling of radio irregularity

Lateration needs (in theory) measurements from:
- 3 non-collinear reference to compute a 2-D position
- Find the point where the three circles overlap

Lateration is computation-heavy (many floating point operations)
- Not an ideal solution when the calculations are done on a node

\[
2 \times \begin{bmatrix}
x_2 - x_1 & y_2 - y_1 \\
\vdots & \vdots \\
x_k - x_1 & y_k - y_2
\end{bmatrix} \times \begin{bmatrix}
x \\
y
\end{bmatrix} = \begin{bmatrix}
x_2^2 - x_1^2 + y_2^2 - y_1^2 + r_1^2 - r_2^2 \\
\vdots \\
x_k^2 - x_1^2 + y_k^2 - y_1^2 + r_1^2 - r_k^2
\end{bmatrix}
\]

\[
\Omega = \frac{1}{2} (\beta^T \times \beta)^{-1} \times \beta^T \times \alpha
\]
Range Based Localisation: Min-Max

- A good simplification models around each anchor node a bounding box and estimates position at the intersection of boxes
  - Performance should be quite similar
  - Number of floating point operations
    - Much lower

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Test Environment: WSN

- Three Node 'roles'
  - Anchor Node: known location
  - Blind Node: unknown location
  - Root Node: datasink - connection to a PC

- WSN Messages
  - Sensor
    - Mote id, Battery (voltage), Light, Humidity, Temperature, Button pressed
  - Location
    - Mote id, Anmoteid, VANs, VANr, Hop count, RSSI
  - Status
    - Mote id, Active, AN, leds
    - Posx, Posy
    - Samplerate, locRate
Test Environment

• Randomly placed Anchor Nodes (black) & 1 Mobile Blind Node (red)

• Tested algorithms:
  • Range less Location estimation
    • Centroid Localisation
    • Weighted Centroid Localisation
  • Range based Location estimation
    • Trilateration
    • Min-Max Localisation
    • Least-Square Trilateration
Test Environment: Software
Test Environment: Calibration

1. Configure anchor nodes with dissemination protocol
   • Set positions & start calibration phase
2. ANs Broadcast in order to measure RSSI
3. ANs Send back RSSI with the collection protocol
4. Use known distances to calculate path loss exponent

\[ PL = P_{T_{\text{dBm}}} - P_{R_{\text{dBm}}} = PL_0 + 10\gamma \log_{10} \frac{d}{d_0} + X_g, \]

\[
\begin{bmatrix}
\text{RSS}1 \\
\vdots \\
\text{RSS}i
\end{bmatrix}
= 
\begin{bmatrix}
-1 & -10\log \frac{d1}{d0} \\
\vdots & \vdots \\
-1 & -10\log \frac{di}{d0}
\end{bmatrix}
\times
\begin{bmatrix}
P(d0) \\
\vdots \\
P(d0)
\end{bmatrix}
\]

Base Mote attached to PC

Anchor 1

Anchor 2

Anchor 3

Blind
Results

- Antenna orientation
  - Non-uniform antenna radiation pattern
  - Onboard microstrip antenna vs omnidirectional antenna
Results

- Comparison of different algorithms
- Outdoor vs Indoor (each dot represents 800 measurements / 15 minutes)
Conclusion

• Overview of WSN localisation algorithms and literature
• Developed a WSN software framework
• Influence of node orientation and antenna selection on RSS
• Comparison of different localisation algorithms
  • In our tests the relatively simple Min-Max algorithm is the best solution
  • But the rangle-less Weighted centroid algorithm has similar performance

• Results published and presented at “European Conference on the Use of Modern Information and Communication Technologies” [9]

Future Work

• Develop extra applications using the system
• Add new types of WSN networks to the system
• Interfacing microcontroller based wall-units

• Use the localisation of nodes in practical applications
• Refine localisation tests
• Test more algorithms (& develop our own algorithms)
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State of the Art / future of Localisation

• Adaptable mobile clients
• Cope with any graspable information
  • GSM, WiFi, WSN, ...
• No dedicated devices
• No proprietary infrastructure
• Outdoor and indoor

• Opportunistic localisation
  • Combine all available localisation sources
State of the Art / future of Localisation
State of the Art / future of Localisation

- Mobile device sensors (in our prototype)
  - GPS, Assisted-GPS
  - Wifi (fingerprinting using RSSI)
  - GSM
  - Motion/step detection
- Particle Filters (sequential non-linear Bayesian Filtering)
  - Model physical characteristics of the movement of an object (motion model)
  - Sequential Monte Carlo methods (SMC): sophisticated model estimation techniques based on simulation

Video
References

http://pi4.informatik.uni-mannheim.de/~haensel/sn_book/


[7] TI CC2420: a single-chip 2.4 GHz IEEE 802.15.4 compliant RF transceiver


Thank you for your attention!

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