Harvesting a Clock from a GSM Signal for the Wake-Up of a Wireless Sensor Network

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Wireless Sensor Networks (WSNs)

- Network of energy-constrained nodes
- Node functionality
  - Sense information
  - Communicate wirelessly
- Potential applications
  - Environmental sensing
  - Biomedical implants
  - Industrial monitoring
- Major design challenges
  - Small volume, low cost
  - Long lifetime → Low-power circuits
Motivation for Synchronization

- Relative power consumption of circuit components on a node

- Duty-cycled communication

![Diagram showing power consumption and synchronization]

- Not synchronized

- Synchronized
Motivation for Synchronization Radio

- Synchronization strategies
  - High-accuracy (high-power) timer
  - Wake-up radio
  - Low-accuracy (low-power) timer + synchronization radio

- Relative power for each synchronization strategy

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<table>
<thead>
<tr>
<th>Strategy</th>
<th>Power Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>HA Timer</td>
<td>1 mW</td>
</tr>
<tr>
<td>WU Radio</td>
<td>1 μW</td>
</tr>
<tr>
<td>Sync Radio</td>
<td>1 nW</td>
</tr>
<tr>
<td>LA Timer</td>
<td>1 pW</td>
</tr>
</tbody>
</table>
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Motivation for Clock Harvesting

- **Timing with a wake-up radio**
  - Unknown time for wake-up signal
  - Wake-up radio on continuously

- **Beacon strategy**
  - Generate within network
    - Requires network power to generate it
    - Requires custom infrastructure
Motivation for Clock Harvesting

- Timing with a synchronization radio
  - Known time for sync signal
  - Sync radio on intermittently

- Beacon strategy
  - Generate within network
  - **Harvest existing signal**
    - Doesn’t require network power to generate it
Motivation for GSM-Based Clock

- Provides worldwide coverage
- Broadcasts high-power signals
- Contains an embedded clock
  - Low-frequency
  - Simple to extract (i.e. low-power)
Characteristics of GSM Standard

- 4 major frequency bands worldwide
  - 850 MHz, 900 MHz, 1800 MHz, 1900 MHz
- 200-kHz bandwidth physical channels
- Basic services (BCCH carrier)
  - Includes...
    - Frequency correction (FCCH)
    - Broadcast control (BCCH)
- Exist on all GSM, GPRS, and EGDE networks

- Channel properties
  - Gaussian minimum shift keying (GMSK) spectrum
  - Constant envelope
Proposed GSM-Based Clock

- Frequency correction burst (FB)
  - Generates tone 67.7 kHz above center freq of BCCH carrier
  - Repeats at rate of approx 21 Hz

Add filter here

Looks like a clock
Proposed Receiver Architecture

- Measures power of BCCH carrier and at FB offset freq
- Uses periodicity of FB as a clock for synchronization

Goal is to harvest a clock, not extract GMSK-modulated data
Proposed Receiver Architecture

- Measures power of BCCH carrier and at FB offset freq
- Uses FB periodicity as a clock for synchronization

Matlab Simulations

Desire signal at output of FB filter only during freq bursts; otherwise, AWGN
Proposed Receiver Architecture

- Measures power of BCCH carrier and at FB offset freq
- Uses periodicity of FB as a clock for synchronization

Expected power similar to wake-up radios previously reported
Proposed Receiver Architecture

- Measures power of BCCH carrier and at FB offset freq
- Uses periodicity of FB as a clock for synchronization

Requires some design, but relatively little power at IF
Proposed Receiver Architecture

- Measures power of BCCH carrier and at FB offset freq
- Uses periodicity of FB as a clock for synchronization

Potentially high power because potentially high-Q, especially narrowband FB filter
Characterization of the FB Filter

- Generated GMSK-modulated FBs and PR bursts
- Set BCCH filter to...
  - 200 kHz bandwidth | 2\textsuperscript{nd}-order bandpass
- Swept FB filter bandwidth and order
  - Generated 10\textsuperscript{4} FB intervals (>10\textsuperscript{8} GMSK symbols)
- Counted number of synchronization errors

- Set FB filter to...
  - 7 kHz bandwidth
  - 4\textsuperscript{th}-order bandpass
Prototype Receiver for Proof-of-Concept

- Set IF to 275 kHz
- Digitized real GSM data
- Used measured data as input to simulated baseband
Extraction of Real GSM-Based Clock

- Counted number of synchronization errors
- Compared simulated and measured results

![Graph showing probability of synchronization error vs. FB filter bandwidth](image)

Similar trends...with discrepancies
Extraction of Real GSM-Based Clock

1. BCCH Path (Ref)

2. FB Path (In)

3. Clock Output
Summary / Conclusions

- Introduced technique of clock harvesting
  - Synchronizes network with existing signal
  - Conserves energy in sensor network
- Identified embedded clock in GSM standard
- Proposed radio architecture for synchronization
  - Amenable to low-power design
  - Characterized probability of synchronization error
- Verified functionality with prototype
- Harvested clock from real GSM signal