Connection Control in Bluetooth

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Outline

• Introduction
• Connection set-up description
• Analytical results
• Simulation results
• Conclusion
Cable Replacement

- Short-range
- Low-cost
- FH

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Description

- ISM band at 2.4 GHz
- Frequency hopping with 1 MHz wide channels
- 79 (23) channels available
- An RF channel divided into 625 µs slots
- One packet is sent in one slot
- Hopping rate 1600 hops/s
- Time-Division Duplex (TDD)
Physical links

- **Synchronous Connection-Oriented (SCO) link**
  - Slot reservation at fixed intervals
  - Supports 64 kb/s symmetric channel
- **Asynchronous Connection-Less (ACL) link**
  - Polling scheme is used
  - Maximal rate 723 kb/s
Packets

frequency

\[ \begin{align*}
  f(n) & \quad f(n+1) & \quad f(n+2) & \quad f(n+3) & \quad f(n+4) & \quad f(n+5) & \quad f(n+6) \\
  \text{Tx} & \quad \text{Rx} & \quad \text{Tx} & \quad \text{Rx} & \quad \text{Tx} & \quad \text{Rx} & \quad \text{Tx}
\end{align*} \]

Max rate (kb/s)

<table>
<thead>
<tr>
<th>forward</th>
<th>reverse</th>
</tr>
</thead>
<tbody>
<tr>
<td>172.8</td>
<td>172.8</td>
</tr>
<tr>
<td>585.6</td>
<td>86.4</td>
</tr>
<tr>
<td>723.2</td>
<td>57.6</td>
</tr>
</tbody>
</table>

625\mu s
A hopping pattern used in a piconet is derived from the address and the clock of the master.
Ad Hoc Networking
Connection Set-Up

- Future master

Inquiry → Page → Connection

- Future slave

Inquiry scan → Inquiry response → Page scan → Connection
Inquiry

- A host broadcasts inquiry messages
- 32 frequencies dedicated for inquiry are split into two trains

![Diagram showing inquiry process with time intervals and frequency allocation]
Inquiry

A future master

host 1
Inquiry scan

host 2
Inquiry scan

host 3
Inquiry scan

address clock

address clock

address clock
A future master

A future slave

Page scan

Page scan

10 ms

address clock
Messages

Future master

Future slave

Inquiry message

Inquiry response

Page message

Page response

Master response

Slave response

Connection set-up

Connection
Scenarios

Inquiry scan | Page scan | Inquiry scan | Page scan
---|---|---|---
Twinscan | Twopagescan | Twinscan | Twopagescan

Inquiry scan | Page scan | sleep | Inquiry scan | Page scan | sleep
---|---|---|---|---|---
Twinscan | Twopagescan | | Twinscan | Twopagescan |

SCO link

Inquiry scan | Page scan
---|---
Twinscan | Twopagescan

Page

A | A | B
| | | |

SCO link

A | A | B
| | | |

Npage

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Approach

- Analysis and simulation

- **Assumptions:**
  - Neither future master nor future slave have other SCO links established
  - $N_{page} = 1$
  - Future master never leaves unsuccessful page
Analytical Approach

Inquiry scan | Page scan | Inquiry scan | Page scan
---|---|---|---
Twingscan | Twpagescan | | 

Xpage

Inquiry scan | Page scan | Inquiry scan | Page scan
---|---|---|---

Xinquiry

Page started

D

Page started

D

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Analytical Results on Average Page Duration

![Graph showing analytical results on average page duration. The graph plots average page duration against Twpagescan (s) with different curves representing different values of p (0, 0.1, 0.3). The y-axis represents average page duration (ms), and the x-axis represents Twpagescan (s). The graph indicates that as Twpagescan increases, the average page duration decreases, and this effect is more pronounced with lower values of p.]
Analytical Results on Average Page Duration

![Graph showing the relationship between Twopagescan / Twinqscan and Average page duration for different Twinqscan times (25 ms, 50 ms, 100 ms, 200 ms, 400 ms). The graph indicates that as the Twinqscan time increases, the average page duration decreases. The formula $p = 0$ is also mentioned.]
Simulation

- BONeS simulation software used
- Bluetooth unit implemented as a finite state machine
- Frequency hopping pattern fully modeled
- Channel assumed to be error-free
- A unit alternates between inquiry scan and page scan
- Upon arrival of data a unit performs inquiry or page
Simulation Results on Average Page Duration

\begin{figure}
\centering
\includegraphics[width=\textwidth]{simulation_results.png}
\caption{Graph showing average page duration vs. Twpagescan (s).}
\end{figure}
Simulation Results on Average Page Duration

![Graph showing average page duration vs. Twingscan time]
Simulation Results on Connection Set-Up Duration

Impact of TwinSCAN on connection set-up duration

Average set-up duration (s)

TwinSCAN (s)

Twpagescan 0.02s
Simulation Results on Connection Set-Up Duration

Impact of Twpagescan on connection set-up duration

- InquiryTO: 2.56s
- ReqNumOfResp: 1
- pageTO: 1
- Npage: 1
- Twpagescan: 0.5s

Average set-up duration (ms)

Inquiry longer

Page longer

Twpagescan (s)

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Conclusion

• Analytical results predict the expected page duration

• An efficient routing algorithm should:
  • Avoid establishing new connections
  • Preserve previously established connections

• Bluetooth technology not suitable for Infostations