On the performance of Bluetooth and IEEE 802.15.4 radios in a body area network

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Emerging
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Goal of the study

Compare the performance of Bluetooth and IEEE 802.15.4 radios for body area networks

- Bluetooth is well-established and available on many handheld devices today
- IEEE 802.15.4 is very popular in the sensor networking world due to its low power and cost

Look at the coexistence of the two radios on-body

Compare across different node positions, activities, packet sizes etc.

Compare the two radios at the MAC layer

- Goodput
- Latency
- Success rates

Experiment setup

Different activities: sitting, standing and walking

Tested on 3 people for each radio

Indoor experiments (office, home)

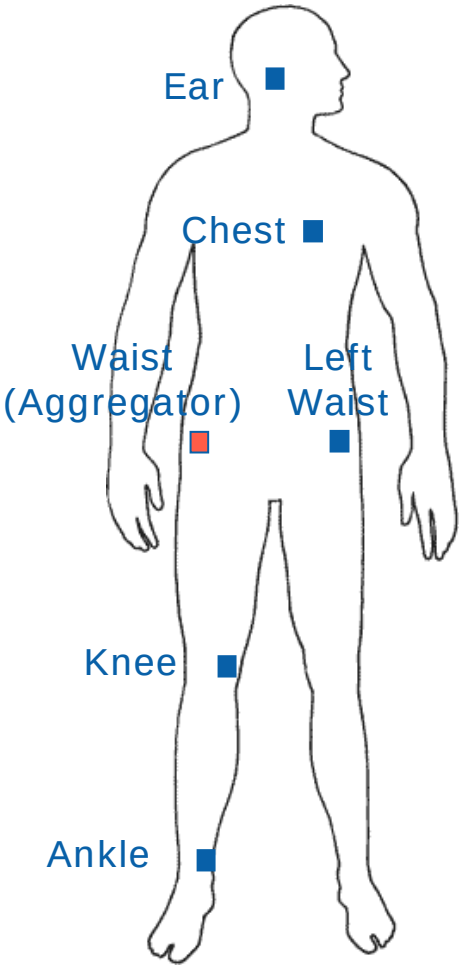
Different packet sizes (10 bytes, 100 bytes)

Data was sent to/from the aggregator on the waist

- Node positions were chosen to mimic typical locations for healthcare applications

Performance metrics:

- Goodput: Bits per second correctly received
- Packet success rate: Fraction of packets correctly received
- Latency: Time since a packet is ready to be sent until the time it is received at the destination



Hardware/software

Bluetooth:

- Intel Mote
- Zeevo module (ARM core and BT 1.1 chipset)
- Retransmissions were automatic
- TinyOS 1.1, interfaced to HCI layer directly

IEEE 802.15.4

- Intel Mote 2
- XScale PXA 271 processor
- Chipcon CC2420 chipset
- TinyOS 1.1, B-MAC

Each experiment consisted of:

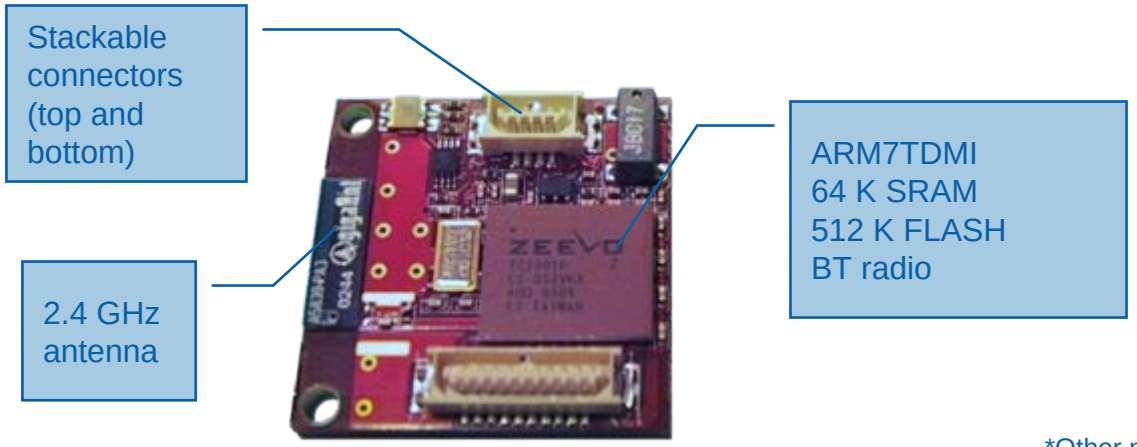
- Packets sent back-to-back for 5 minutes
- Correctly received/missed packets were recorded to flash
- IEEE 802.15.4: Channel 11 was used

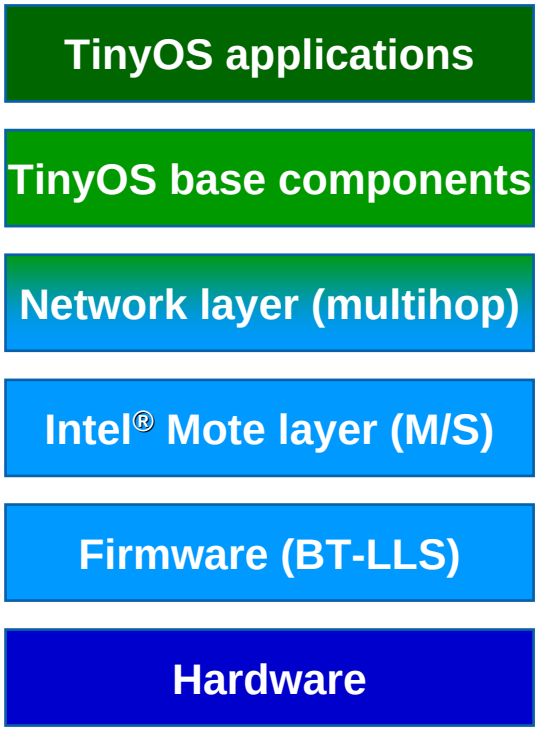
Intel® Mote

Based on TinyOS (UC Berkeley)
- Ported to ARM* architecture

Intel® Mote specific layer
- BT support
- Platform device drivers

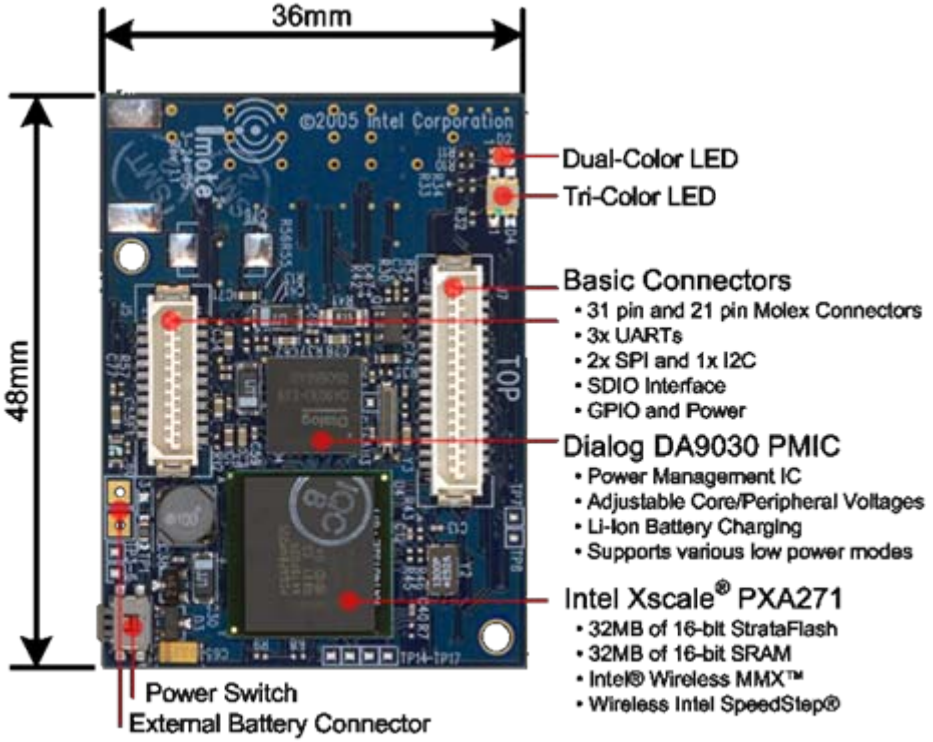
Network layer
- Topology establishment
- Single- and multi-hop routing
- Interfaces to HCI layer



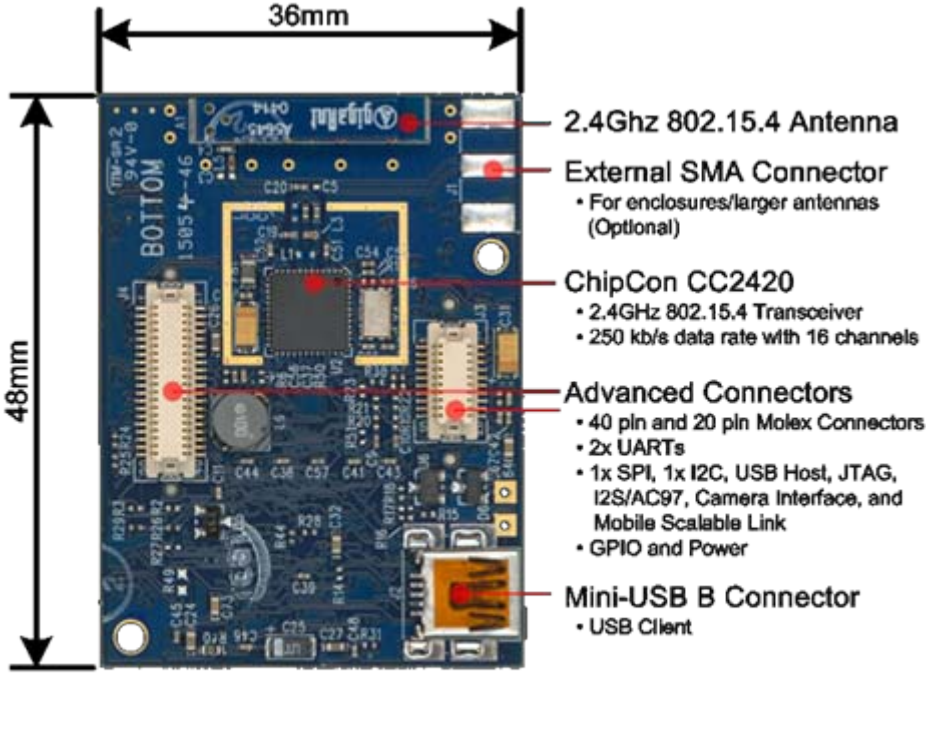


*Other names and brands may be claimed as the property of others

Intel Mote 2



– Top –



– Bottom –

Multi-radio support

- 802.15.4 on main board
- BT on a plug-in board

Multiple OS support

- TinyOS 1.1, TinyOS 2.0
- Linux
- SOS
- .NET Micro Framework

Baseline (free space) results

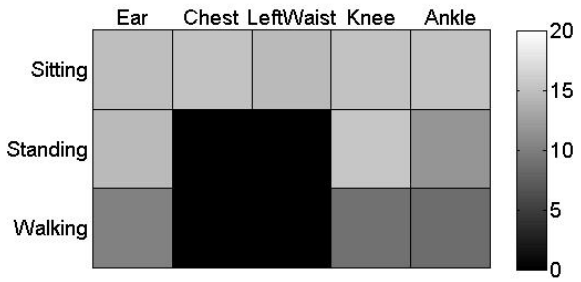
Packet size (bytes)	Goodput (kbps)	Success rate (%)	Mean latency (ms)
802.15.4			
10	16.43	98.94	4.82
100	94.63	99.78	8.44
Bluetooth			
10	12.36	100.00	6.47
100	115.03	100.00	6.95
300	232.20	100.00	10.34

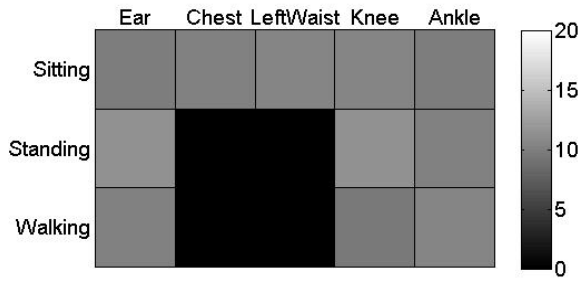
Nodes placed 1 meter apart

Single sender node

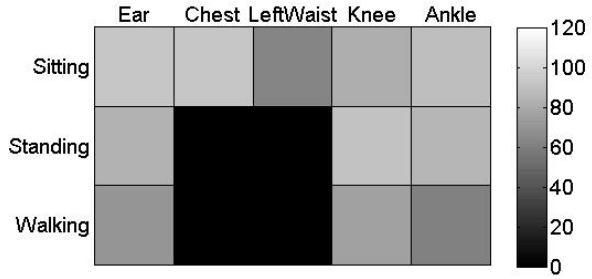
Performance across different people

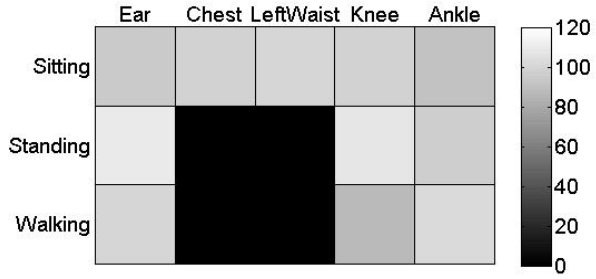
10 byte packets





100 byte packets





802.15.4

Bluetooth

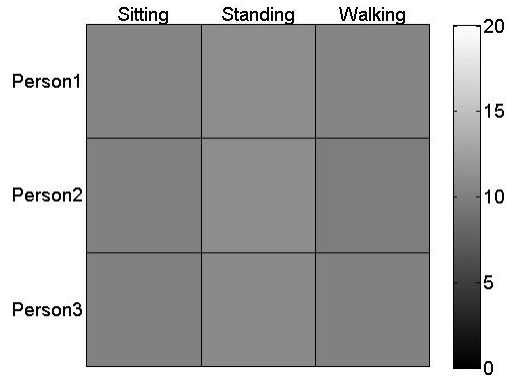
802.15.4 performed better for small packets; BT was better for large packets

802.15.4 performed significantly worse when walking (for small packets)

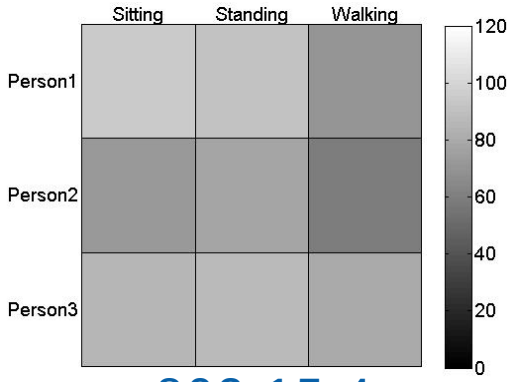
Generally speaking, Bluetooth was much more consistent

Performance across different node positions

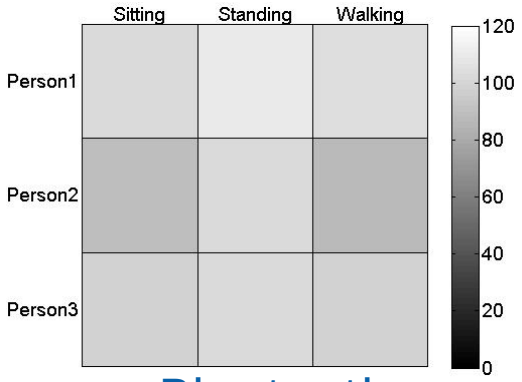
10 byte packets



100 byte packets



802.15.4



Bluetooth

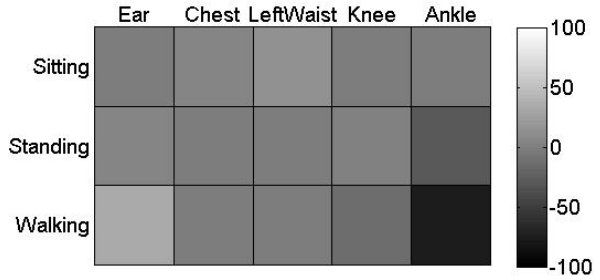
802.15.4 had higher goodput for small packets

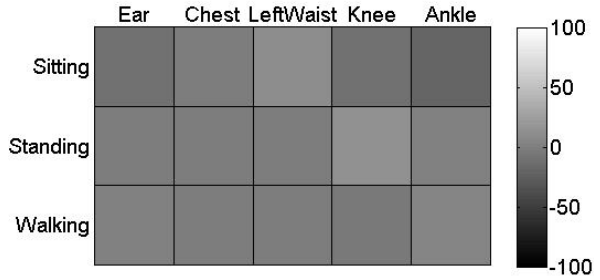
Blueetooth had higher goodput for large packets

802.15.4 had more variation across activities, people

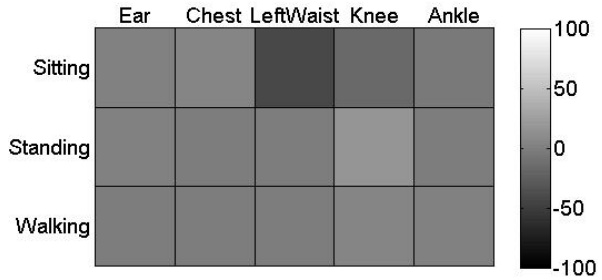
Bidirectional performance

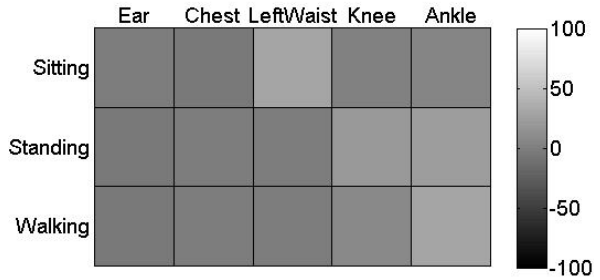
10 byte packets





100 byte packets





802.15.4

Bluetooth

The performance was more or less symmetric to/from the aggregator

802.15.4 had slightly more variation than Bluetooth

Latency comparison

	10 byte packets		100 byte packets	
	802.15.4	BT	802.15.4	BT
Ear	5.45	7.69	8.48	7.97
Knee	7.08	7.68	8.47	8.39
Ankle	7.17	7.92	8.47	8.56

Latencies are in milliseconds

More or less constant, except for the ear for 802.15.4

Channel fade measurements

	Avg. fade duration (ms)	Max. fade duration (ms)
Ear	15.48	10640
Knee	15.32	7377
Ankle	17.08	6758

These measurements are only available for 802.15.4

Average fade durations last the length of a few packets

The maximum fade durations can be very large

Adding retransmissions to 802.15.4

	Ankle to waist		Waist to ankle	
	With retx	Without retx	With retx	Without retx
10 byte packets				
Goodput (kbps)	10.33	11.88	9.7	13.37
Success rate (%)	100.00	90.12	100.00	90.03
Latency (ms)	8.13	7.17	8.41	5.24
100 byte packets				
Goodput (kbps)	45.89	78.36	57.43	80.55
Success rate (%)	100.00	85.62	100.00	87.94
Latency (ms)	18.08	8.47	14.06	8.49

These results are for a single person (while sitting) only

Acks (necessary for retransmissions) reduce the goodput and increase latency significantly

Multiple sender nodes

Multiple sending nodes for 802.15.4

	10 byte packets		100 byte packets	
	Goodput (kbps)	Success rate (%)	Goodput (kbps)	Success rate (%)
Ankle	2.50	40.67	16.43	49.63
Chest	3.20	51.33	45.27	74.90
Overall	5.70	46.65	61.70	68.17

Results are averaged across 3 people, all sitting

Going from 1 to 2 sender nodes reduced the aggregate goodput significantly

- For 10 byte packets, aggregate goodput dropped ~55%
- For 100 byte packets, aggregate goodput dropped ~23%

One of the nodes gets starved of bandwidth (100 byte packets case)

Multiple sending nodes for Bluetooth

	10 byte packets		100 byte packets	
	Goodput (kbps)	Success rate (%)	Goodput (kbps)	Success rate (%)
Ankle	4.80	100	37.20	100
Chest	4.90	100	45.50	100
Overall	9.70	100	82.70	100

Results are averaged across 3 people, all sitting

Going from 1 to 2 sender nodes reduced the aggregate goodput marginally

- For 10 byte packets, aggregate goodput dropped ~8%
- For 100 byte packets, aggregate goodput dropped ~12%

None of the nodes gets starved of bandwidth

Radio co-existence

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Coexistence of the two radios

	Experiment 1		Experiment 2	
Packet size	BT (ear to waist)	15.4 (ankle to waist)	BT (ankle to waist)	15.4 (ear to waist)
10 bytes	12.31	1.90	9.38	0.40
100 bytes	84.62	43.19	86.41	10.87

Results are goodput figures (in kbps)

Experiment setup:

- These results are for a single person (sitting) only
- One radio was placed on the ear, other radio on the ankle
- Both nodes sent data to aggregator devices on the waist

Bluetooth ends up clobbering IEEE 802.15.4

Comparison summary

	10 byte packets		100 byte packets	
	802.15.4	Bluetooth	802.15.4	Bluetooth
Baseline	16.43	12.36	94.63	115.03
Best activity	13.92	11.01	86.48	104.71
Best node position	15.30	10.50	92.95	101.32
Best person	13.24	10.74	84.58	105.24
Average across all data	12.82	10.44	80.02	99.09

Results for 802.15.4 are for the no-retransmission scenarios

802.15.4: Best activity – standing, best node position – chest, best person – person 1

Bluetooth: Best activity – standing, best node position – ear, best person – person 1

Observations

Bluetooth goodput was lower than expected, possibly the packet types were not optimized correctly

Generally, Bluetooth had lower goodput for 10 byte packets, and higher goodput for 100 byte packets

Using acks and retransmits improved the success rate of 802.15.4 but reduced the goodput dramatically

Overall, IEEE 802.15.4 performance was more erratic than Bluetooth

IEEE 802.15.4 performance was particularly bad when

- Multiple nodes sent data to the aggregator
- Both radios were used simultaneously

Conclusions

Bluetooth seems to be better suited for BAN networks in terms of performance and reliability

Power comparison is left as future work

- Difficult to directly compare the two radios since Bluetooth consumes power to maintain a connection
- Bluetooth power consumption is likely to be higher than 802.15.4
- Sniff mode in Bluetooth can reduce its power consumption, but then the latency will go up

Backup

Summary data (802.15.4)

	10 byte packets		100 byte packets	
	Goodput (kbps)	Success rate (%)	Goodput (kbps)	Success rate (%)
Baseline	16.43	98.94	94.63	99.78
Best activity (standing)	13.92	94.82	86.48	91.62
Best node position (chest)	15.30	97.69	92.95	98.68
Best person (person 1)	13.24	93.10	84.58	92.40
Average across all data	12.82	91.50	80.02	86.95

Results are for the no-retransmission scenarios