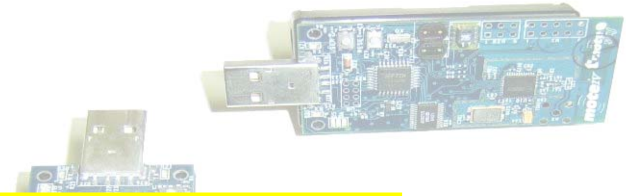
Design Issues and Experiences with BRIMON Railway BRIdge MONitoring Project



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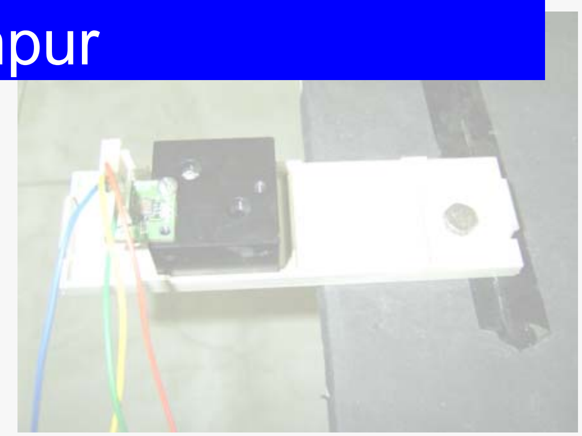

Supervisor:

Dr. Bhaskaran Raman

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BriMon

Goal

- A low cost and scalable Structural Health Monitoring (SHM) system for remote monitoring of railway bridges.

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Introduction

- Indian Railways:
  - 63,140 Km long network
  - More than 14 million people moved daily
  - More than a million ton of goods transported daily

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Safety is important

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Safety is important

- Railway Bridges
  - More than 120,000 bridges
  - 44% older than 100 years
  - 74% or > 89,000 are more than 60 years old

Introduction

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Safety is important

- Railway Bridges
  - More than 120,000 bridges
  - 44% older than 100 years
  - 74% or > 89,000 are more than 60 years old

On-demand, cost effective and scalable solution required

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Introduction (Contd.)

- Often major rail accidents occur due to failure of railway bridges
  - 140 year old bridge failed at Kadalundi in Kerla, on 22nd June 2001 killing 57 people.
  - 12 people killed due to derailment at a weak culvert (12th May 2002)
  - Rafiganj train disaster 10th September 2002 killing more than 130 people.

**Image source: Online news articles, Internet search*

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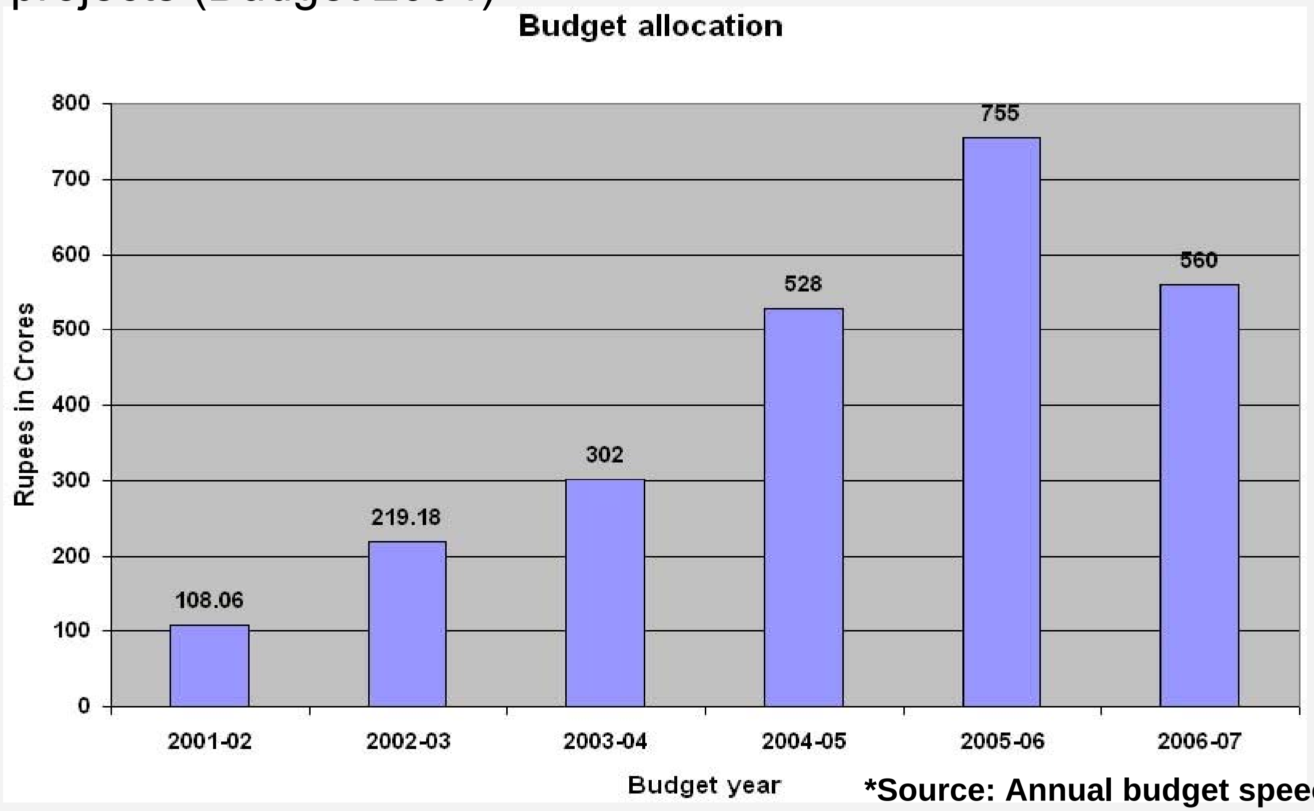
Introduction (Contd.)

- Measures by govt.
  - Increased expenditure by the government
  - Interaction with IIT's and other research institutes for Bridge engineering research projects (Budget 2004)



*Source: Annual budget speeches

Current state

- Currently available bridge monitoring systems are wired systems.
  - Bulky equipment
  - High cost
  - Require planning and laying down of cables, can need days to weeks for set up.
  - Skilled labor requirement
  - Large power requirement
  - Cannot be left on site/ operated autonomously
  - Problems with old structures

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Current state (Contd.)

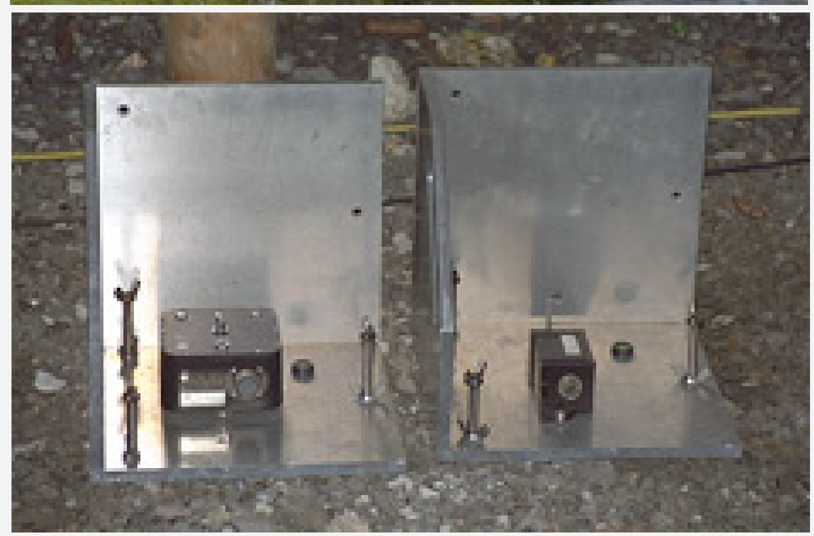

*Image source: www.brimos.com

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Current state (Contd.)

Image source: www.brimos.com, Internet search

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Current state (Contd.)

- Existing wireless solution
  - Single hop (non scalable)
  - Not low power or energy aware (short life)

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Problem statement

- Record the structural response of a railway bridge by measuring vibrations.
  - Accelerometers are placed on piers of bridge, separated by 5-60 m.
- Data needs to be time-stamped & collected with high reliability and fidelity.
- Low cost and easy to deploy.
- Autonomous & on-demand data gathering.

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Thesis Contribution/Uniqueness

- Complete system design
  - Auxiliary circuits
  - Integration
  - Data transportation
- Customized Time synchronization protocol
- Event detection for data gathering

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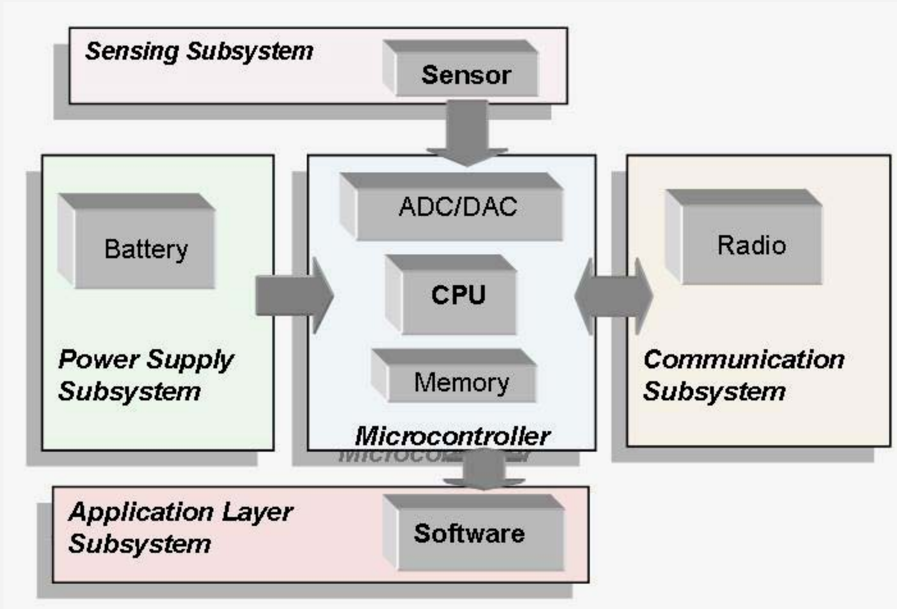
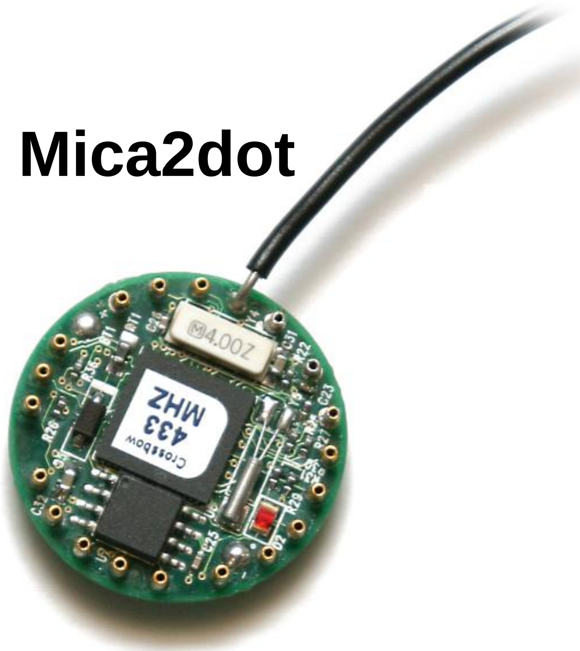
Wireless Sensor Network (WSN)

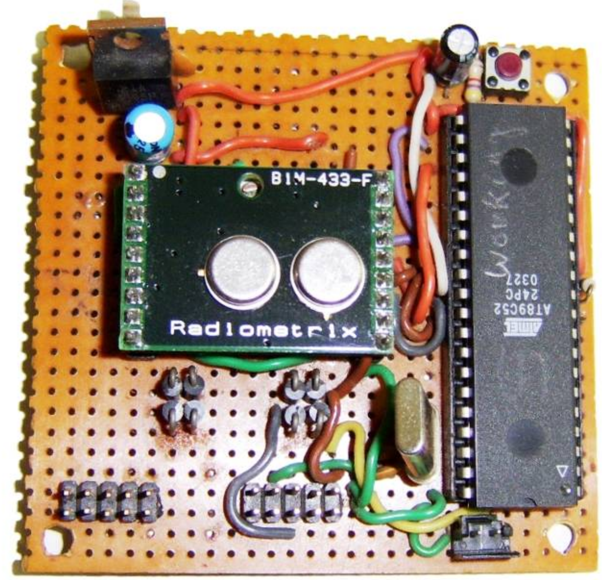
- A WSN consists of a collection of small, low powered, (ideally) inexpensive assembly.
- Limited capabilities.
- Numerous parameters.
- Multi-hop and duty cycling for extended range and life.
- Low power sensors.



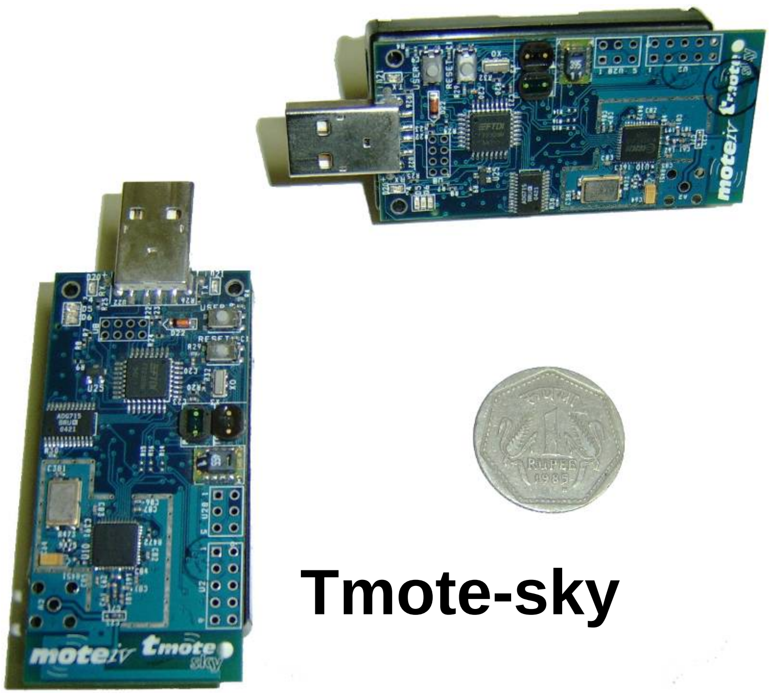
Mica2dot



MicaZ

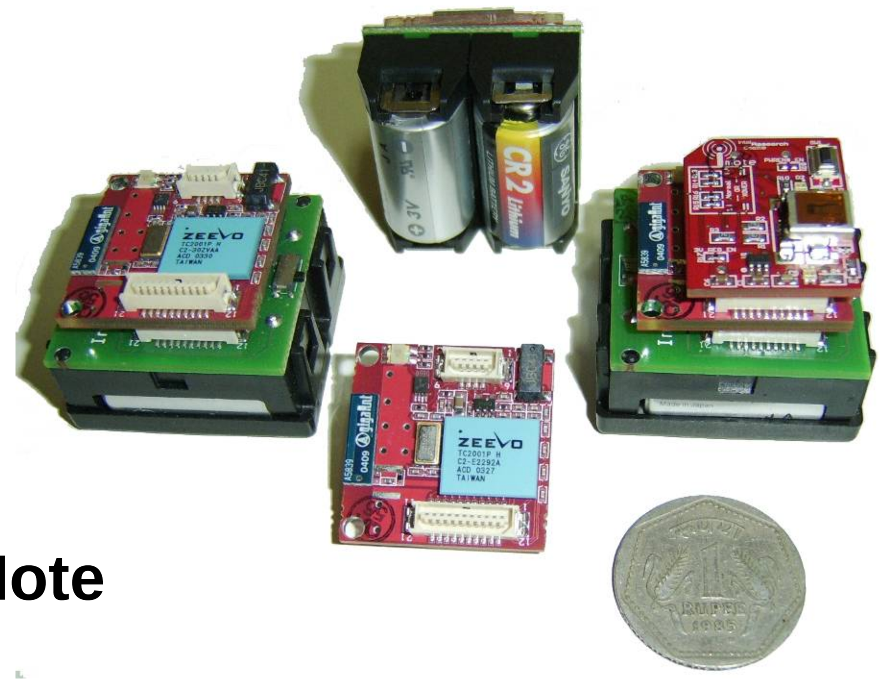


IITK mote
(Ver. 1)



Tmote-sky

iMote



	Habitat Monitoring	Predictive Monitoring	ZebraNet	Volcano Monitoring	NetSHM	BriMon
Deployment Period (Documented)	4 months	19 weeks & 6 weeks	3 weeks	3 weeks	Short Term	Long Term
Sensors Used	Temperature, Humidity & Barometric Pressure	Accelero-meters	Global Positioning System (GPS)	Seismoacoustic sensors	Accelero-meters	Accelero-meters
Mote's Radio Range	10s of meters	10s of meters	100s of meters	100s of meters	10s of meters	100s of meters
Power Source (Battery type)	Li ion	Alkaline	Li ion (Recharge-able)	Alkaline	N.A.	Li ion (Recharge-able)
Time Synchroniza-tion Method	TASK	None	GPS	FTSP	FTSP	FTSP
Data Collection (Period)	Periodic (5 & 20 min)	Periodic (7 & 21 hrs)	Periodic (8 min)	Continuous & Event Based	Continuous	Periodic & Event Based (weeks)
Architecture	Tiered	Tiered	Flat	Flat	Tiered	Tiered
Mote Level Computing	Raw data Collection	Raw data Collection	Raw data Collection	Event Detection	Raw data Collection	Raw data Collection

Comparison of wireless sensor network based applications
*(**TASK**: Tiny Application Sensor Kit, **FTSP**: Flooding Time Synchronization Protocol)*

Structural Health Monitoring (SHM)

- SHM systems are used for
  - Damage detection
  - Damage localization
  - Lifespan prediction
- Vibration measurements with accelerometers
- Use of forced, free, and ambient vibrations
- Band of interest: 0-50Hz

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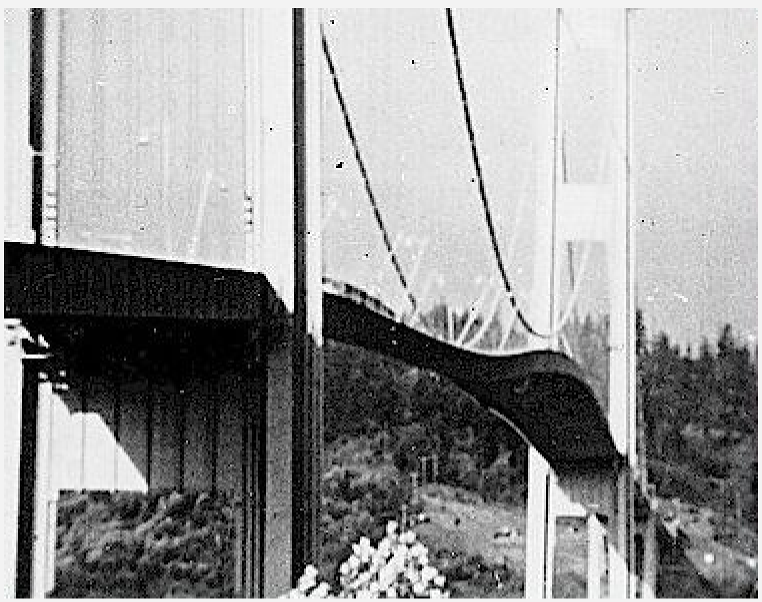
WSN applications in SHM

	WISDEN	Golden Gate Monitoring	Predictive	NetSHM	BriMon
Motes used	Mica-2	Mica-2	Mica-2 & iMote	MicaZ	Tmote-sky
Accelerometer characteristics	100 mV/g with 300 μgrms noise	ADXL203 & SD1221	Wilcoxon 786A	± 2.5 g tri axial	ADXL203
Data compression method	Run length coding Wavelet (proposed)	None	None	None	None
Time synchronization method	In network residence time compensation	N.A.	None	FTSP	FTSP
Architecture	Flat	Flat	Tiered	Tiered	Tiered

SHM and Bridges

- Natural frequencies and standing waves
- Modes as signature of the structure



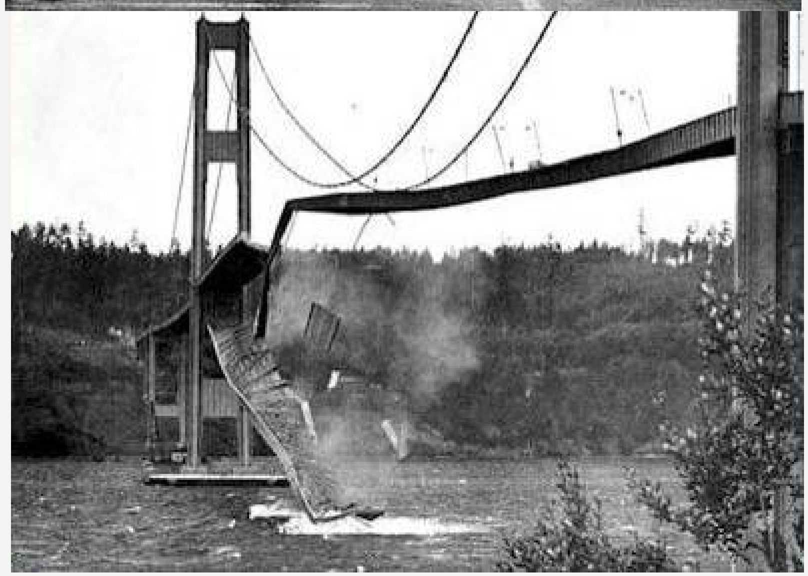


**Image source: Special archive University of Washington*

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Time Synchronization

- Need for time synchronization
  - Correlation of data from different nodes
  - Additional tasks: MAC, synchronized wake-up.
- Sensor nodes are distributed, independent but coordinating systems.
  - Separate clocks
  - Shared wireless channel
  - Broadcast medium (any one in range can listen)

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Time Synchronization (Available Methods)

- Global clock at each node
  - (Global positioning system) GPS
- Global clock at one node and clock correction by beaconing
  - RBS, TPSN, FTSP
- Time synchronization post data collection
  - Post-facto synchronization

Details?

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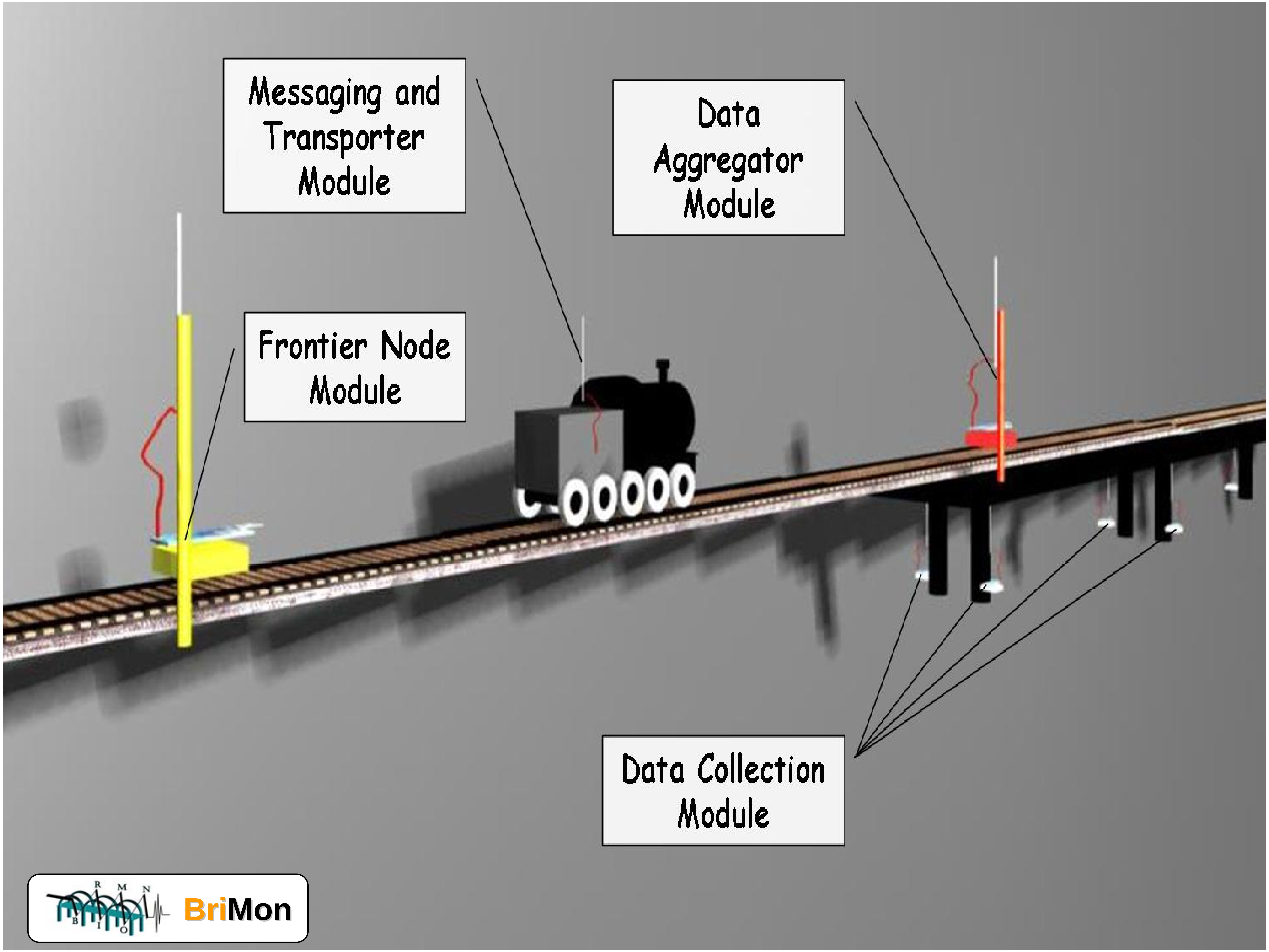
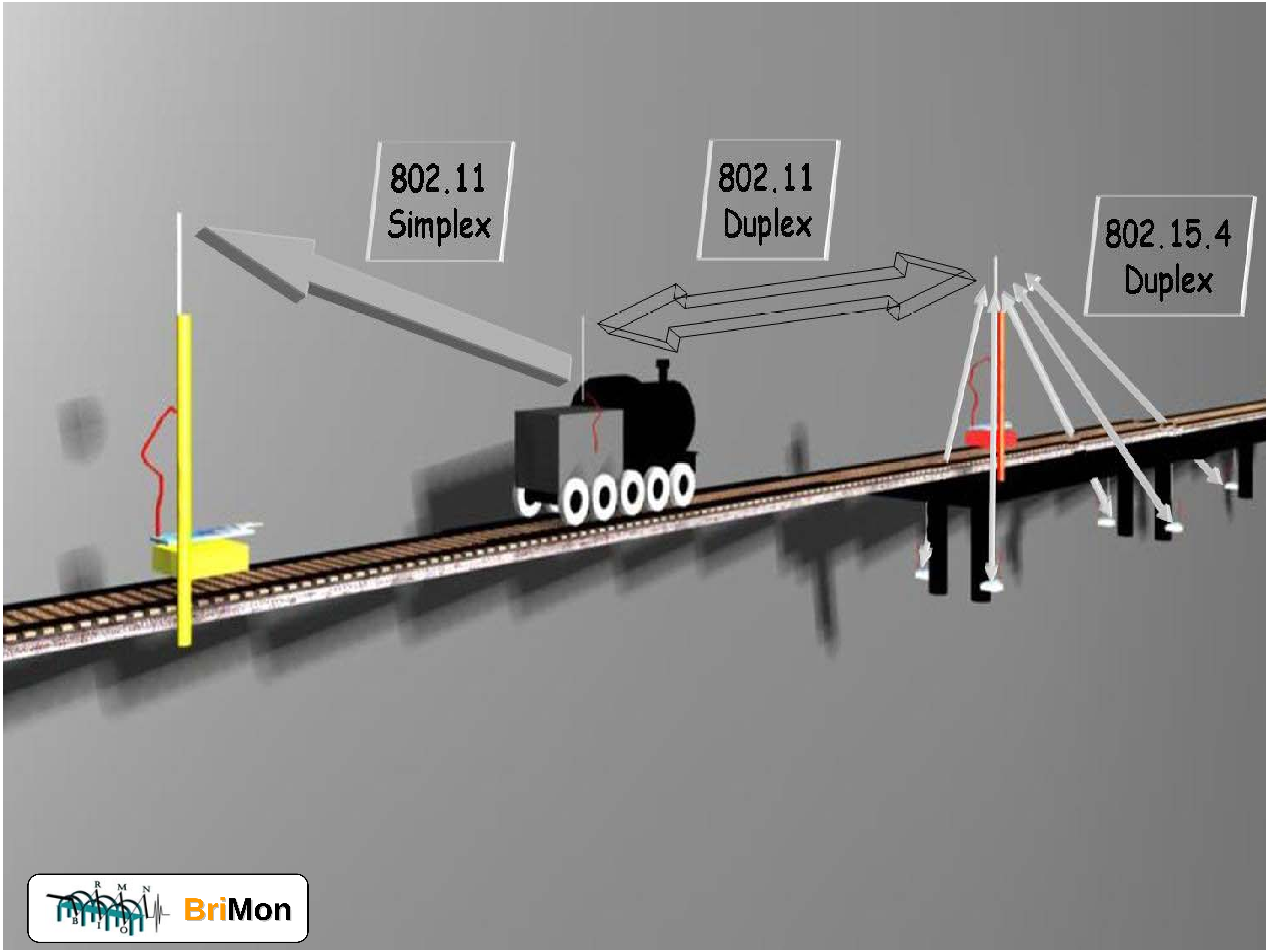

Messaging and Transporter Module
Data Aggregator Module
Frontier Node Module
Data Collection Module
BriMon


802.11
Simplex
802.11
Duplex
802.15.4
Duplex
BriMon

Time Synchronization

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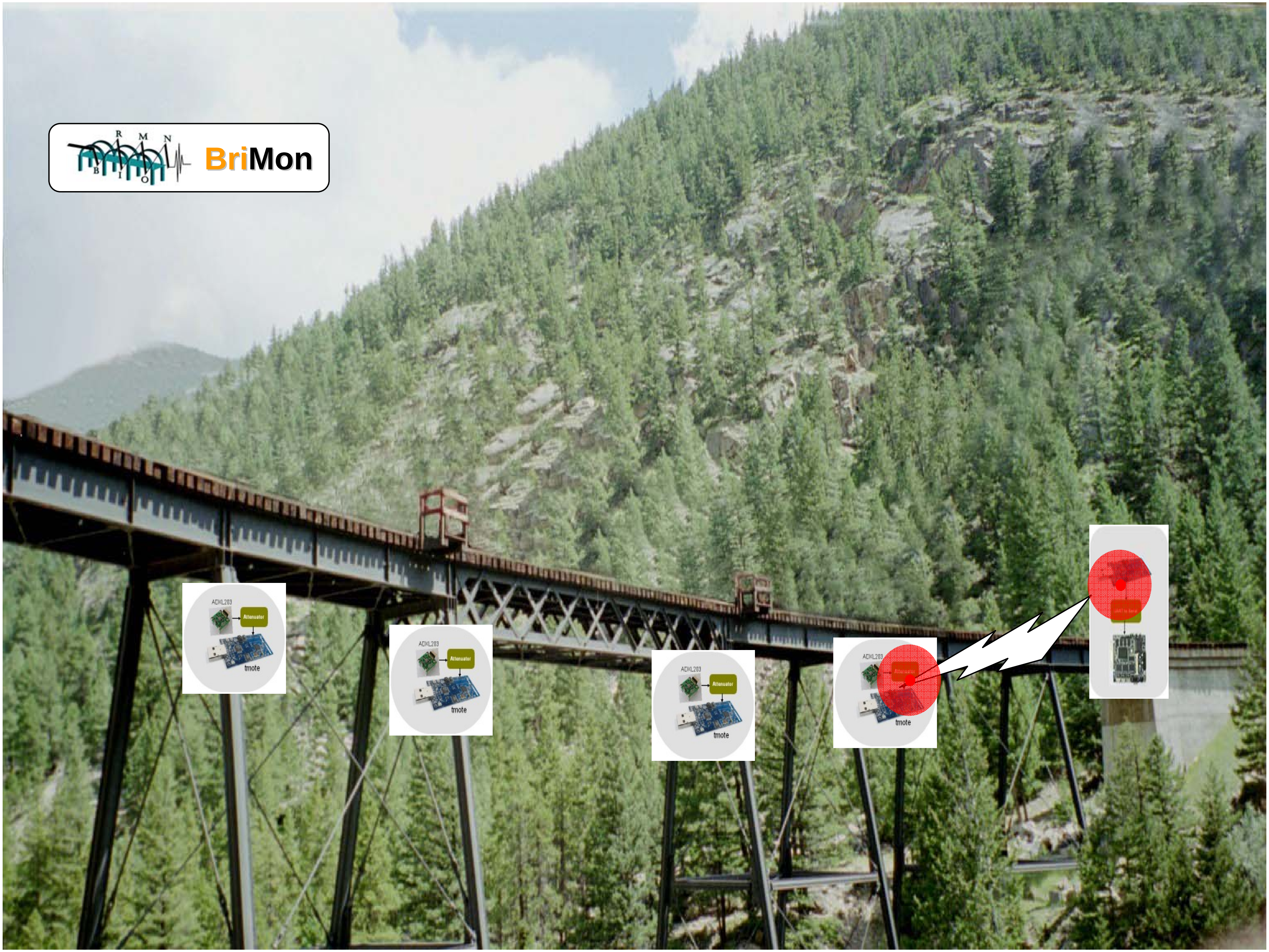
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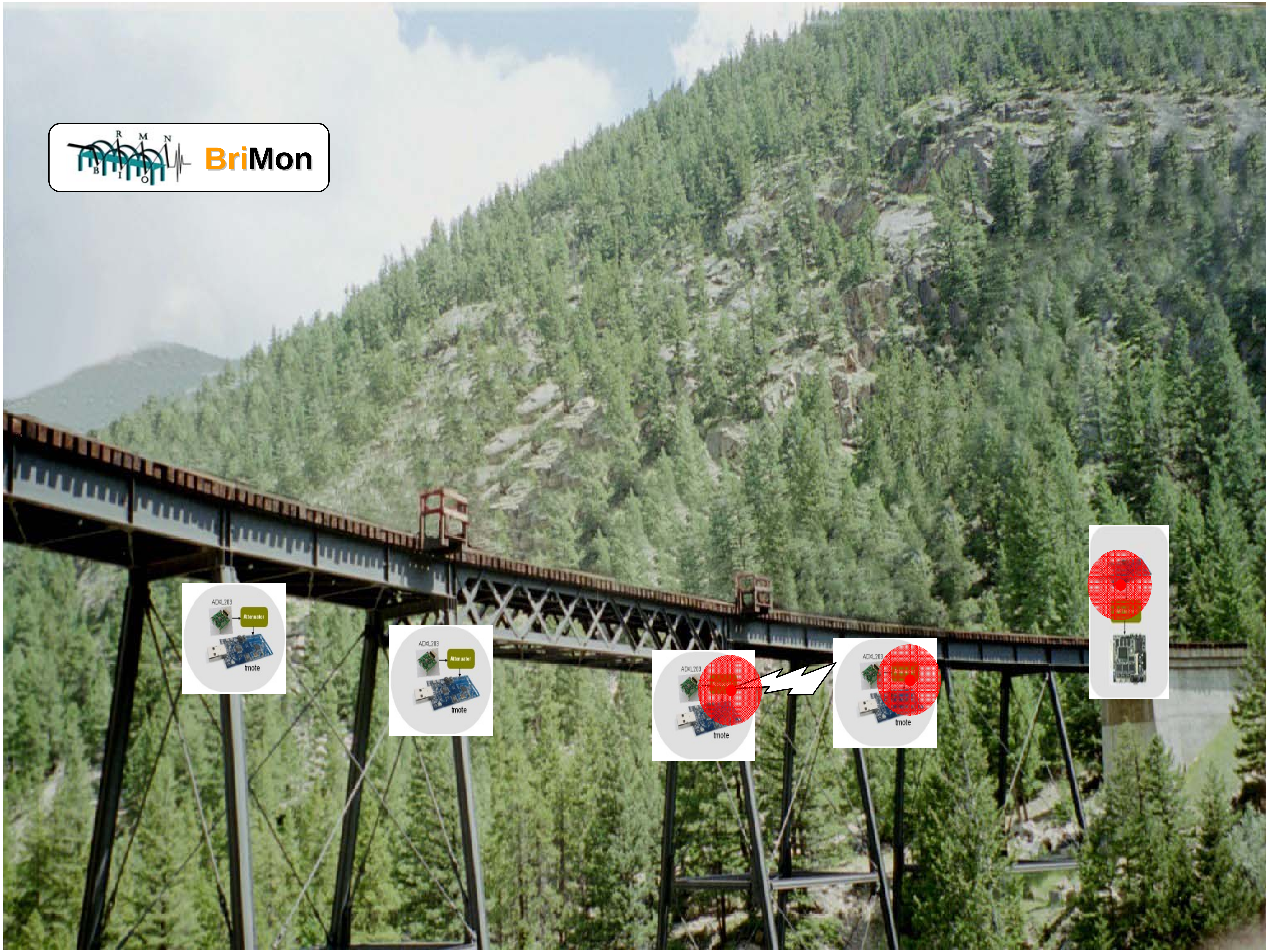
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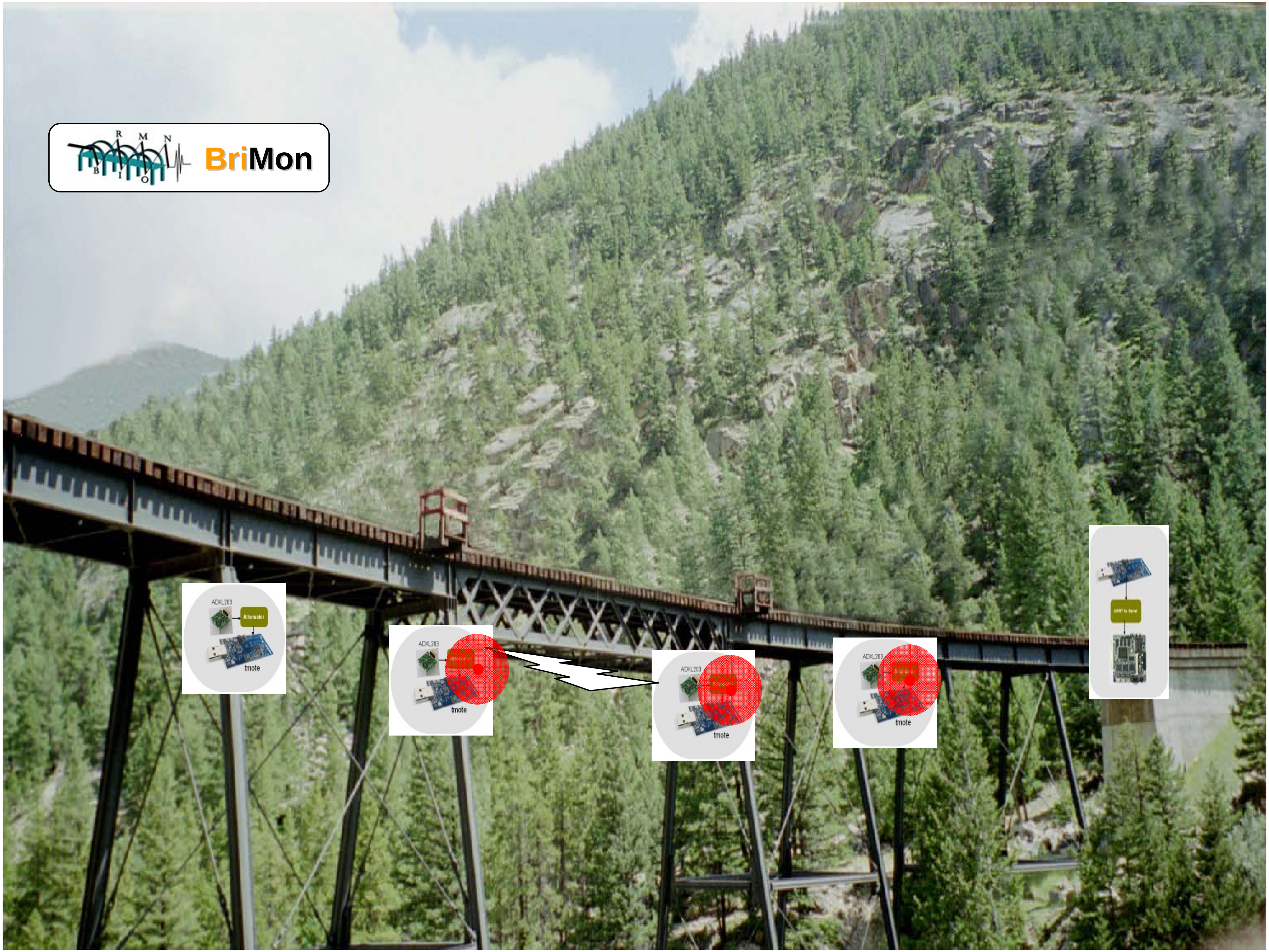
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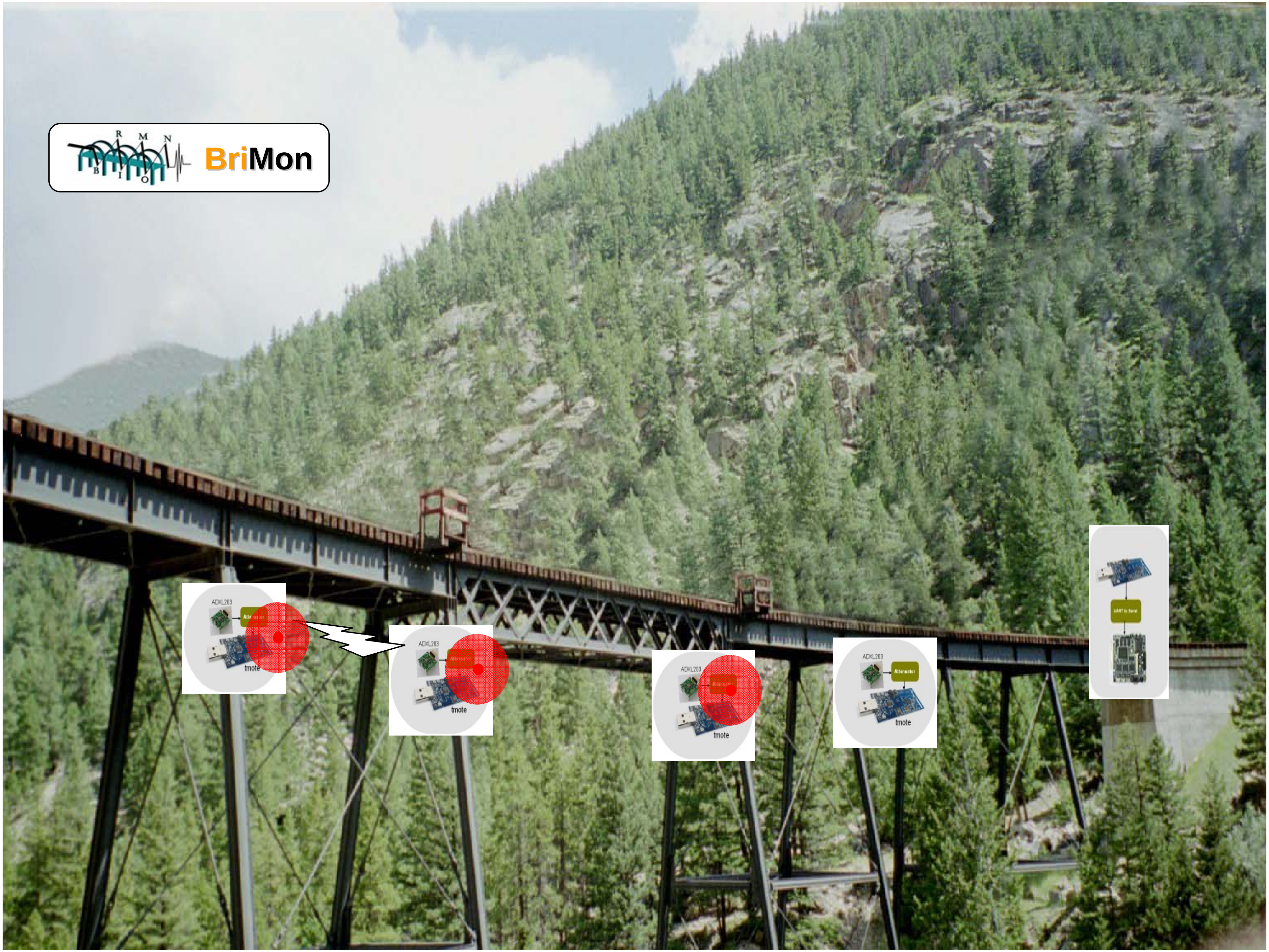
UART to Serial


BriMon
ADXL203
Attenuator
tmote

Event Detection & Data Transfer

(detection of incoming train)

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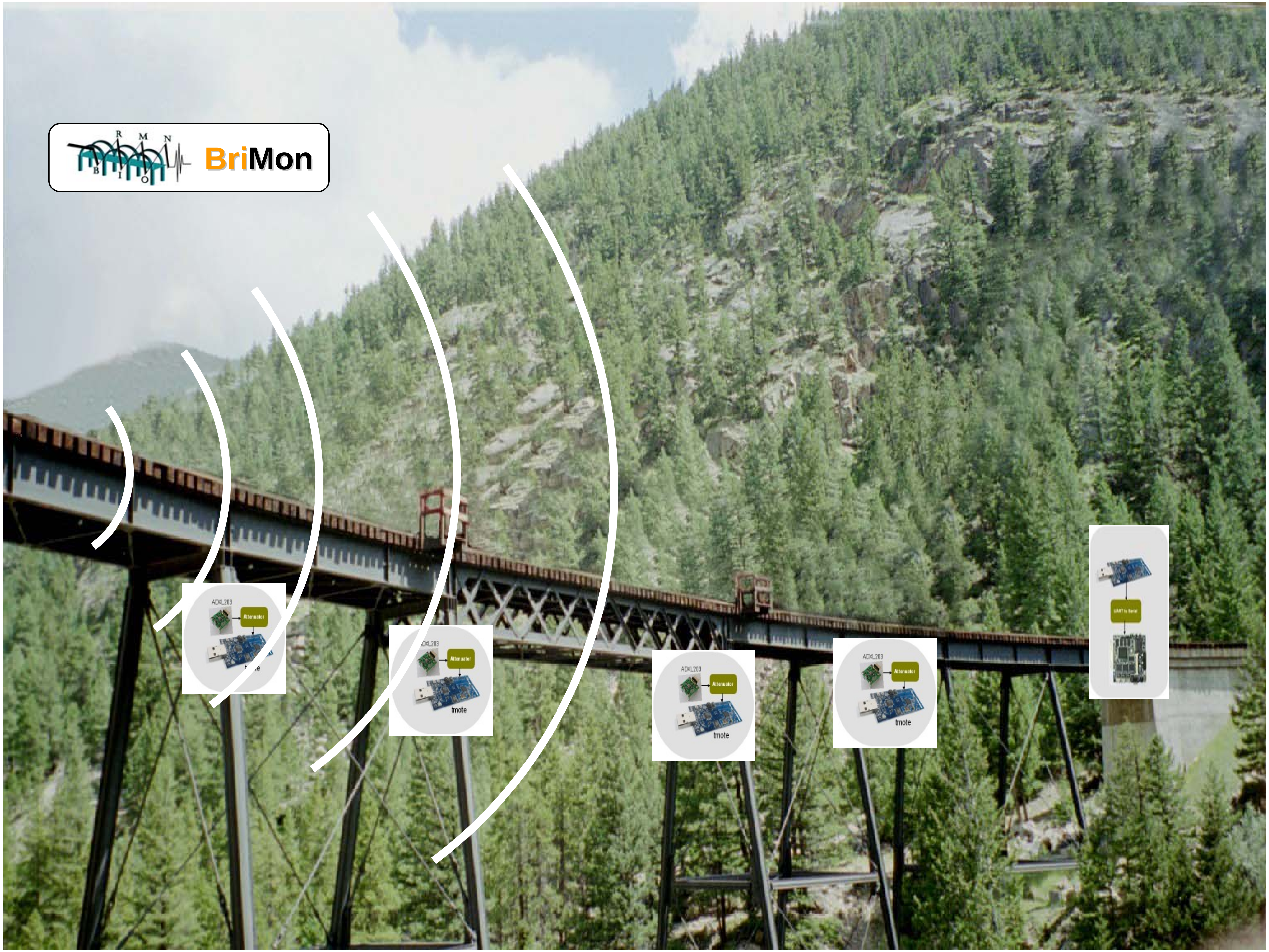
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Attenuator
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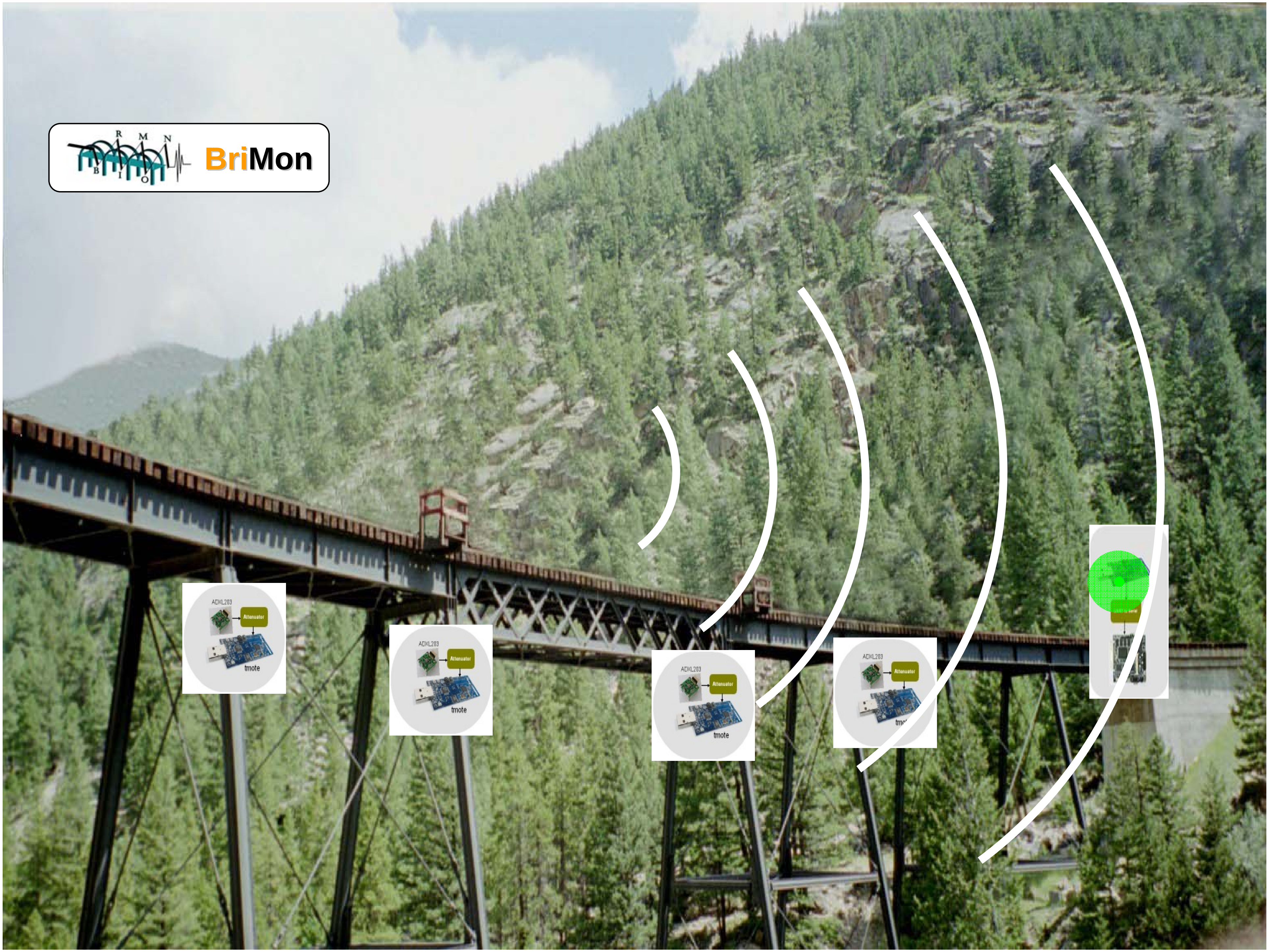

BriMon
ADXL203
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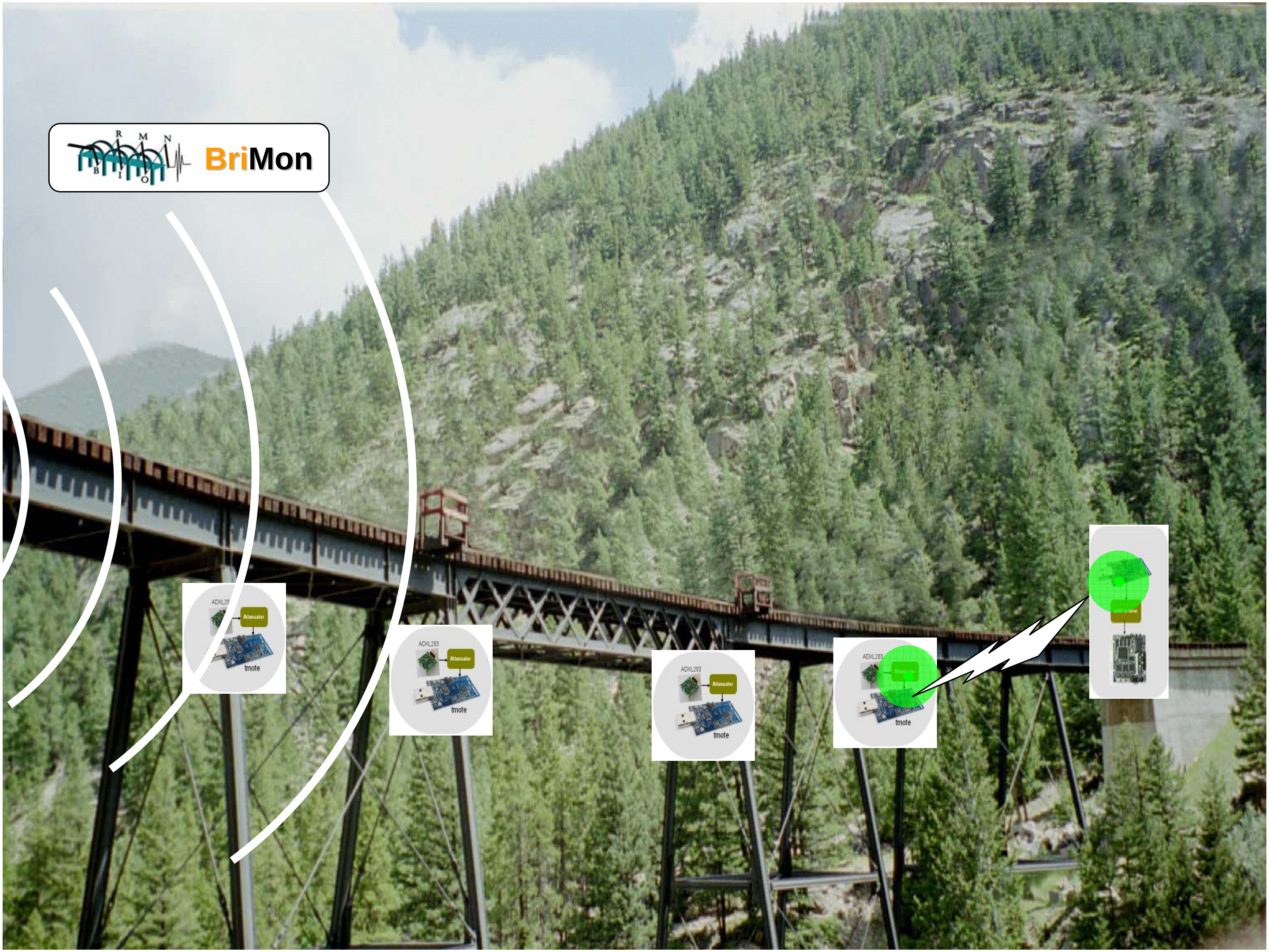
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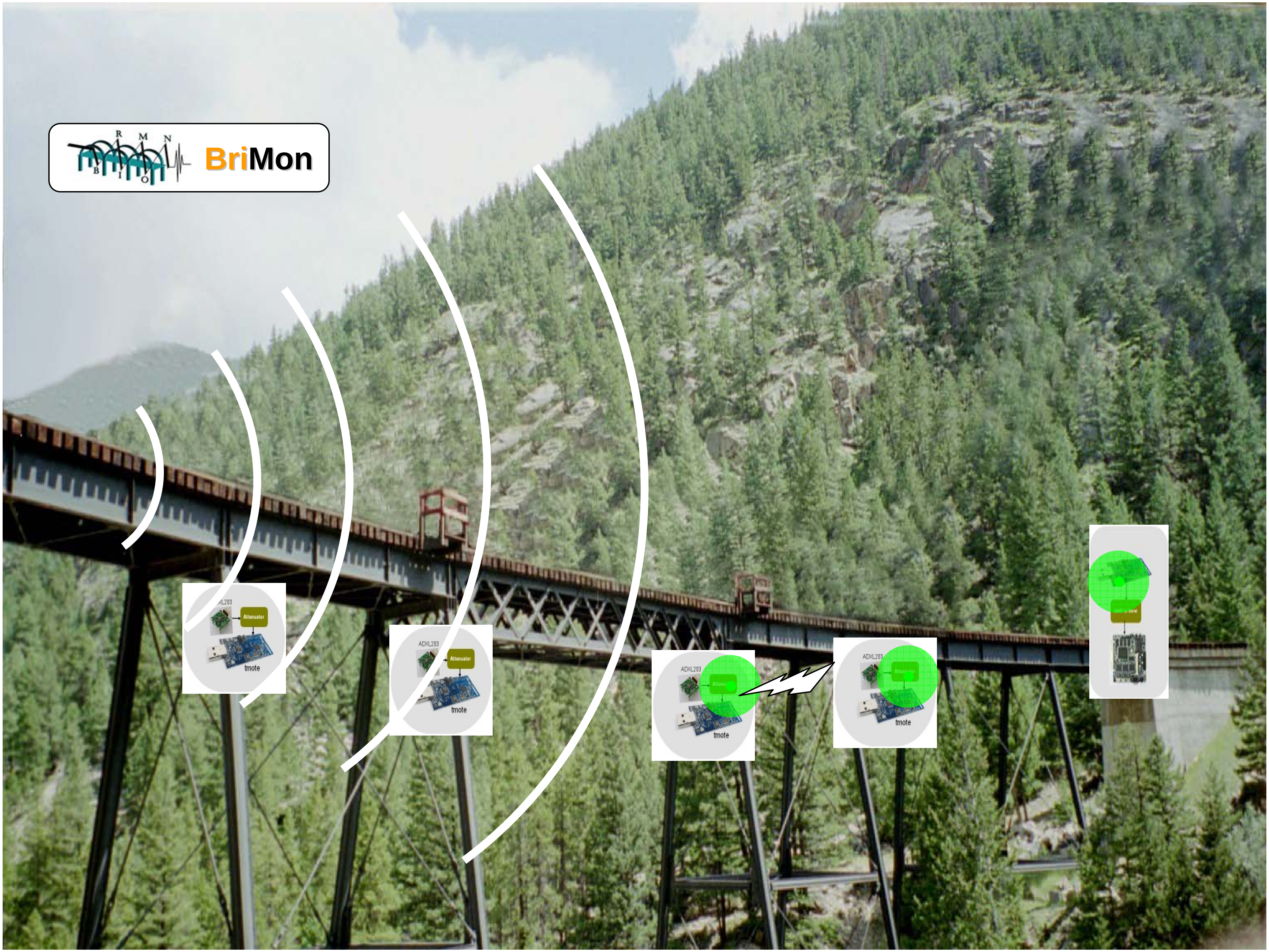
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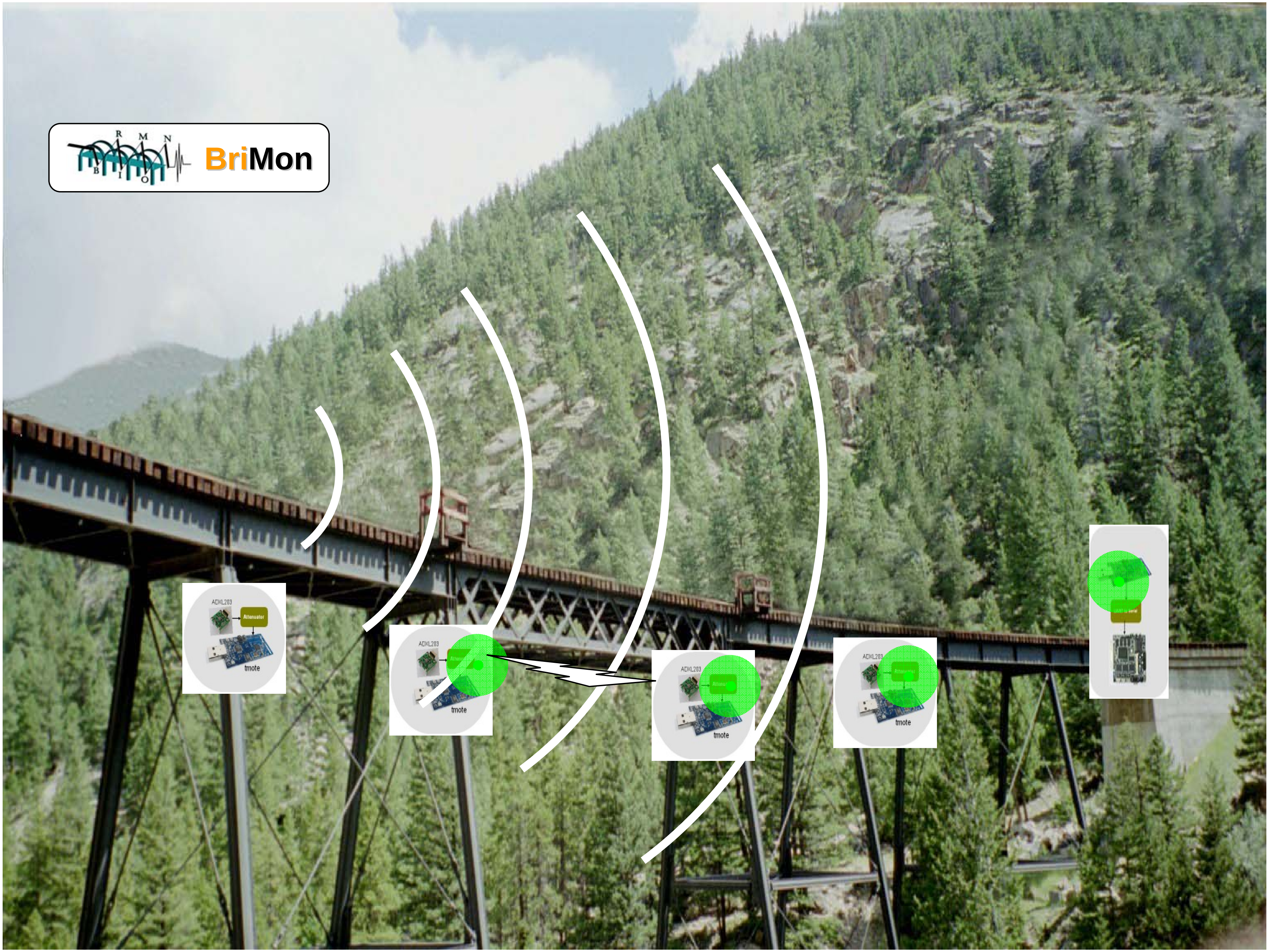
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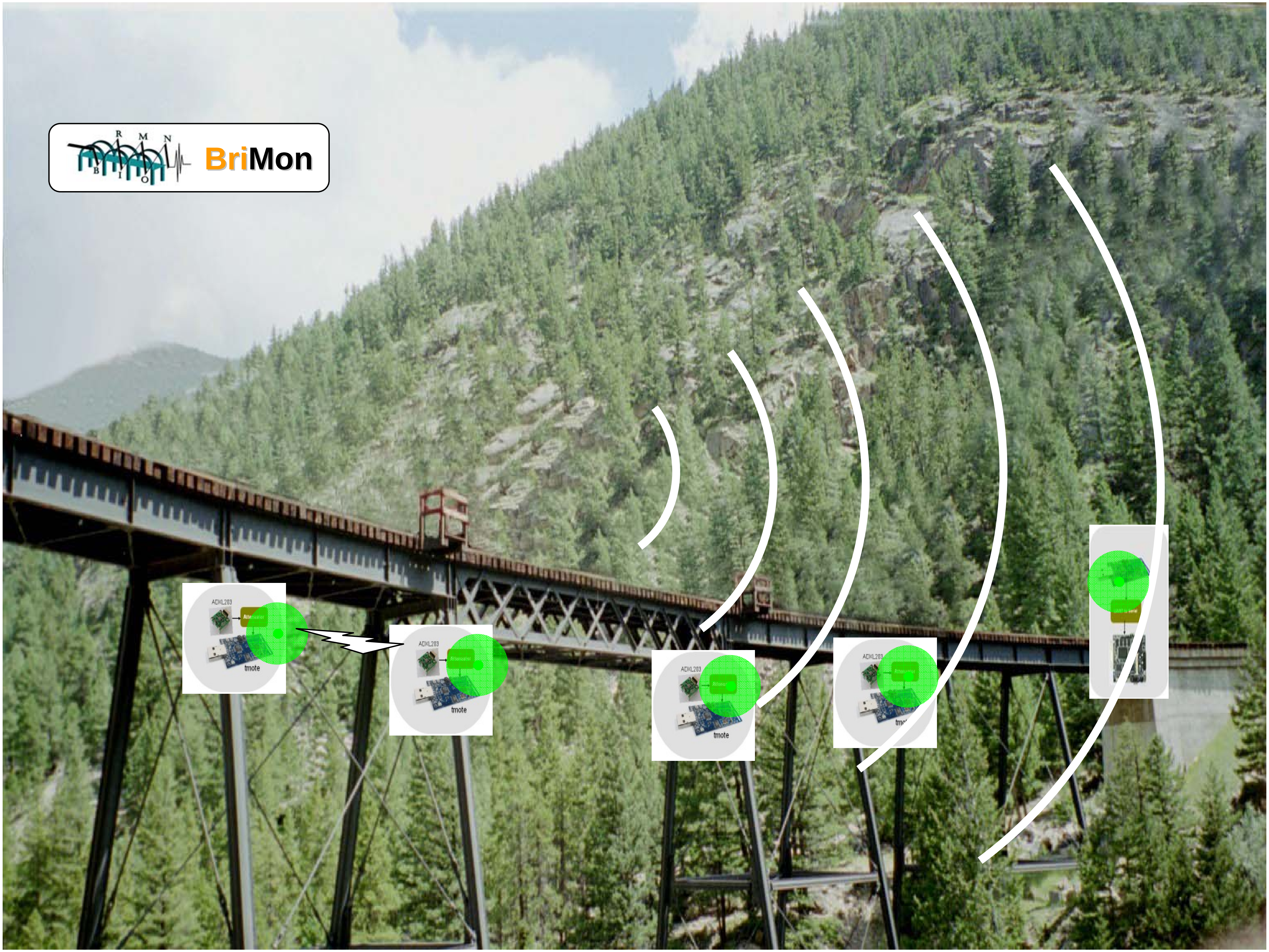
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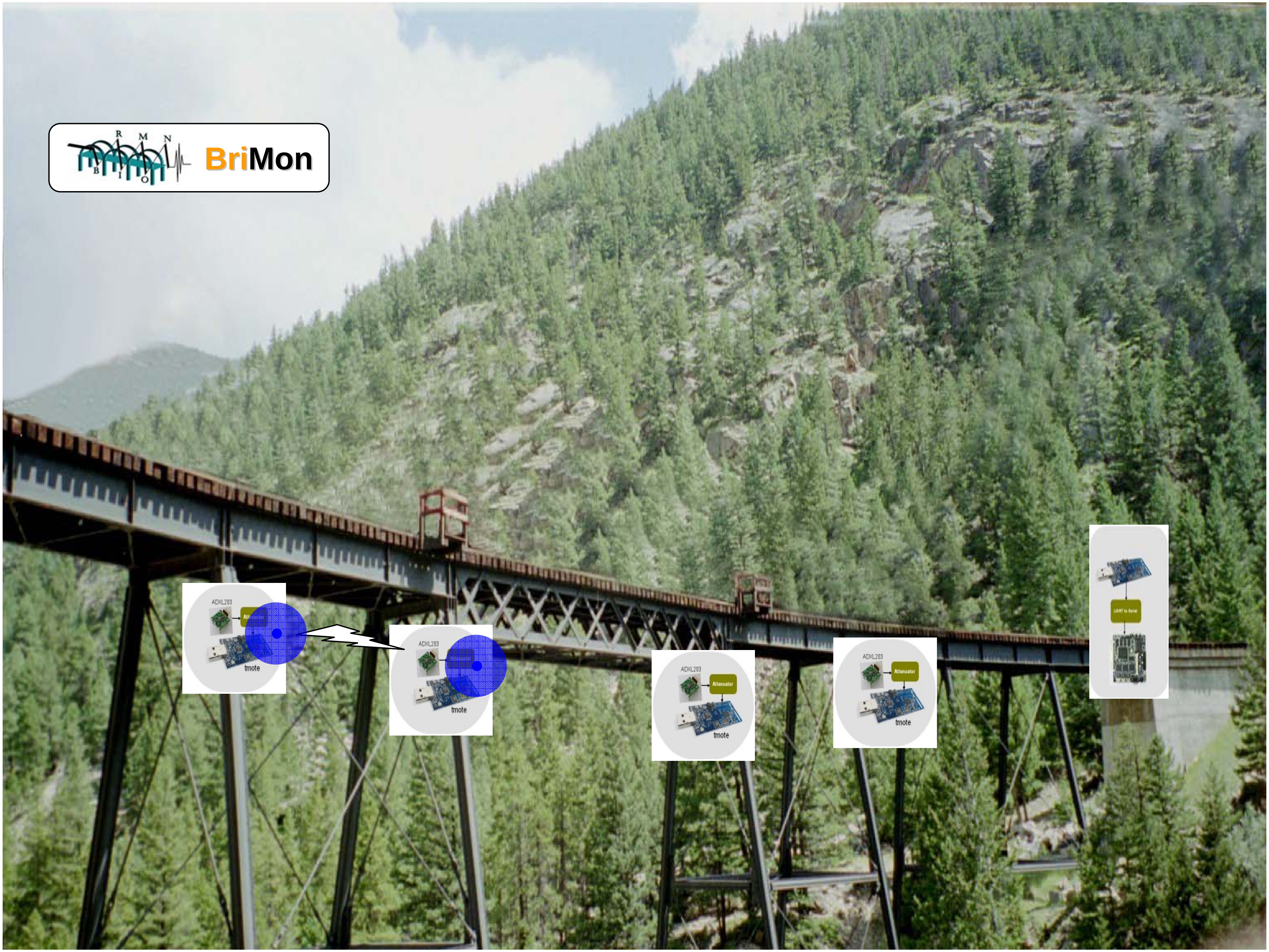
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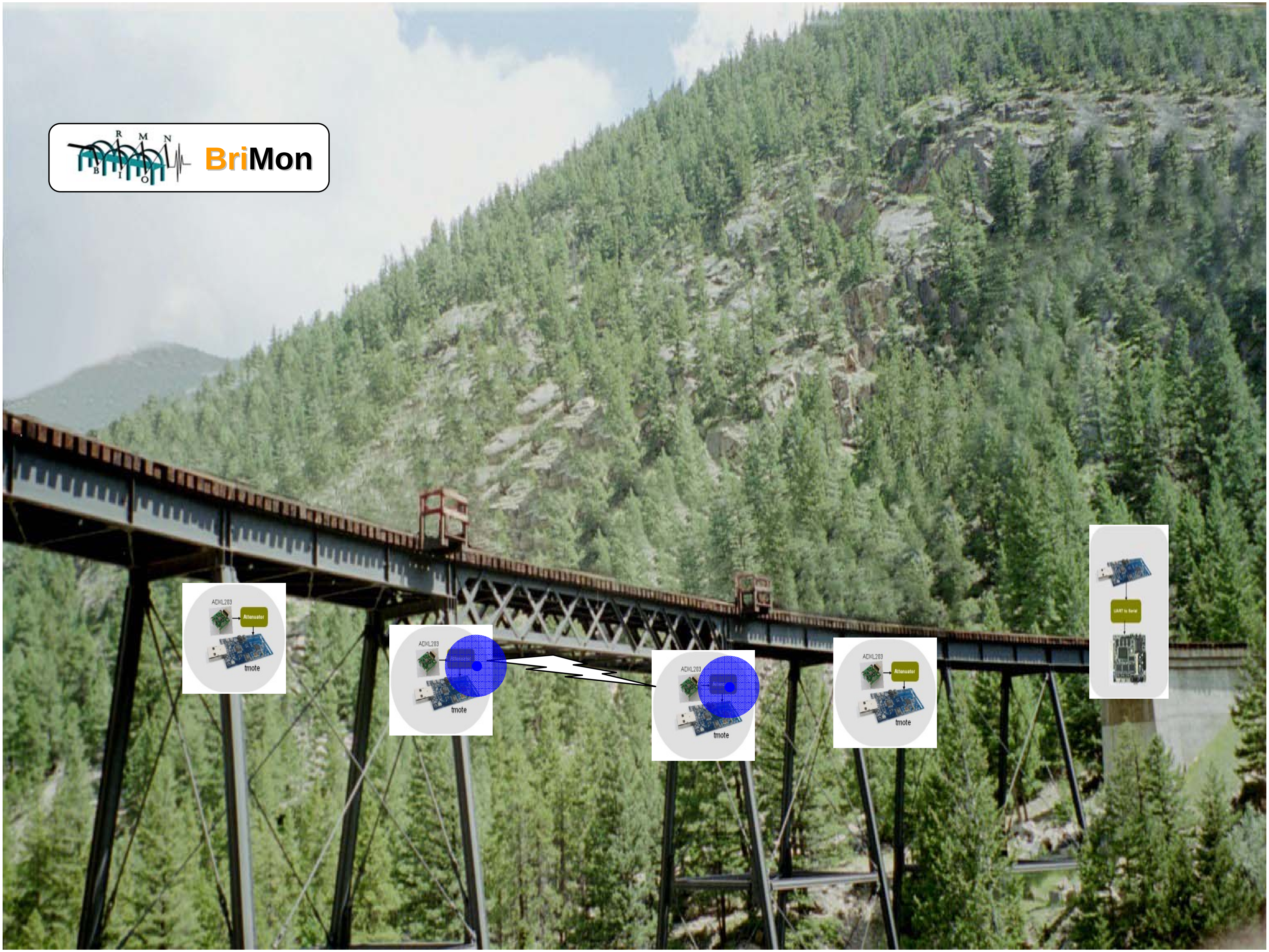
UART to Serial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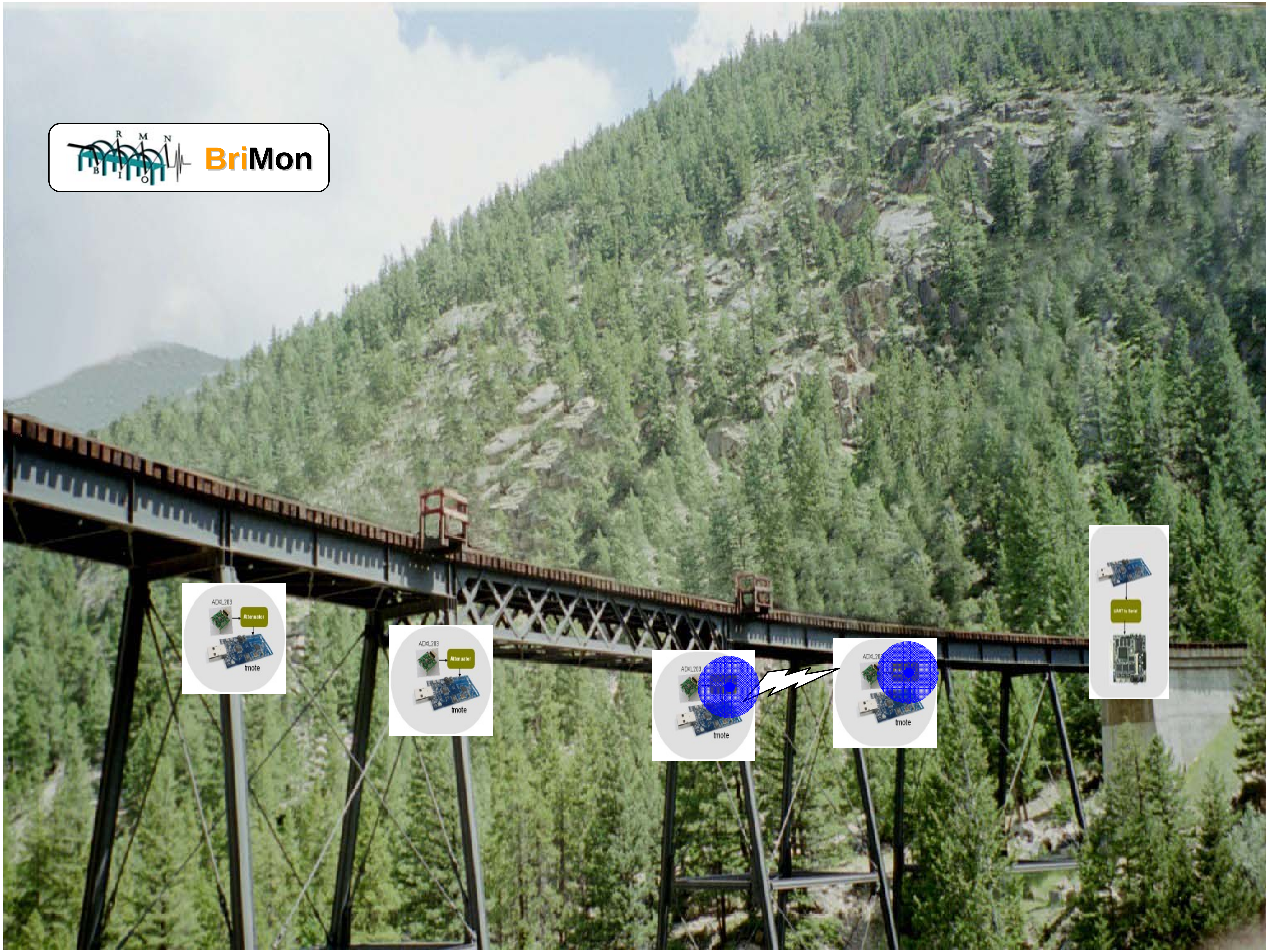
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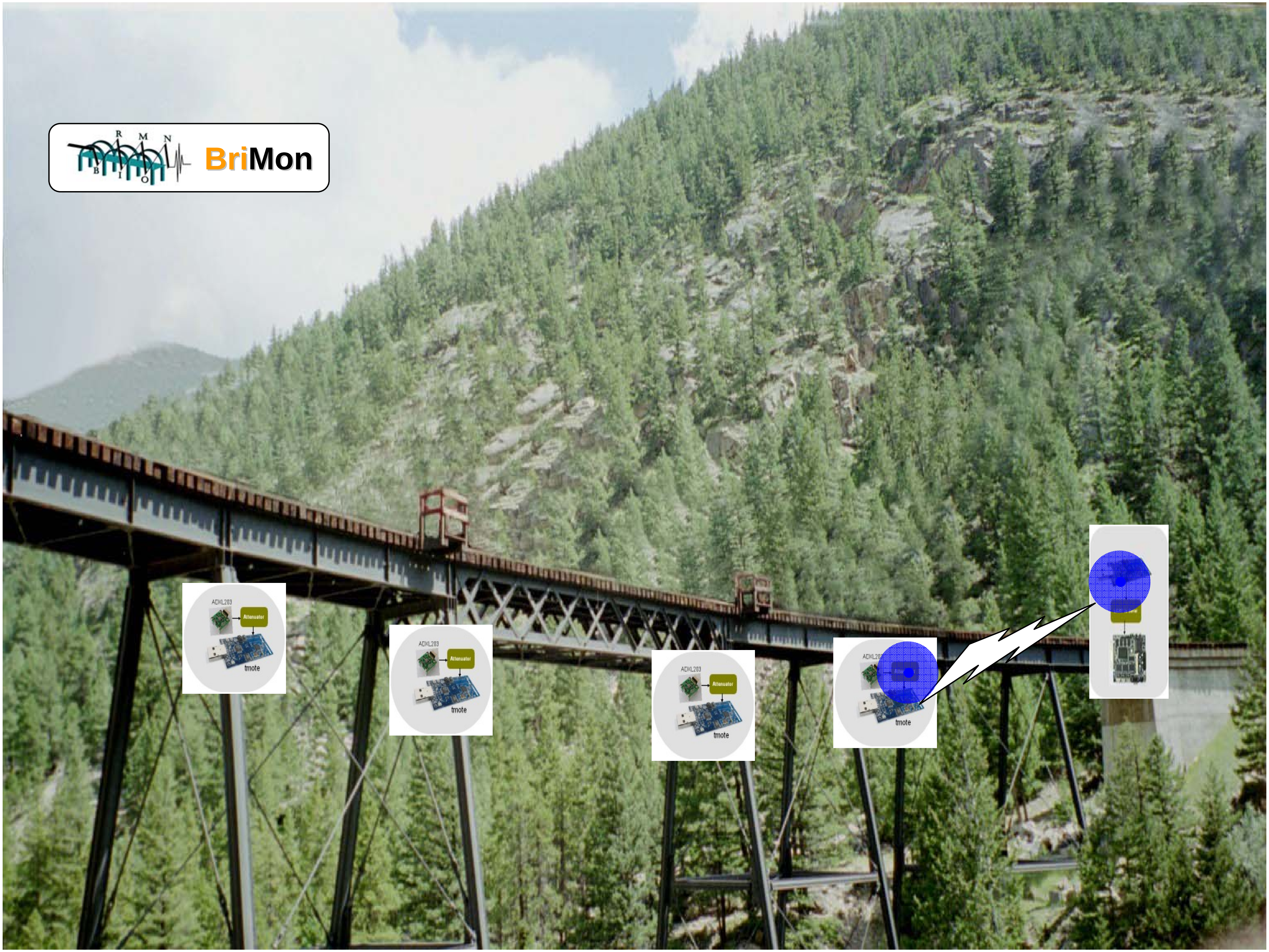
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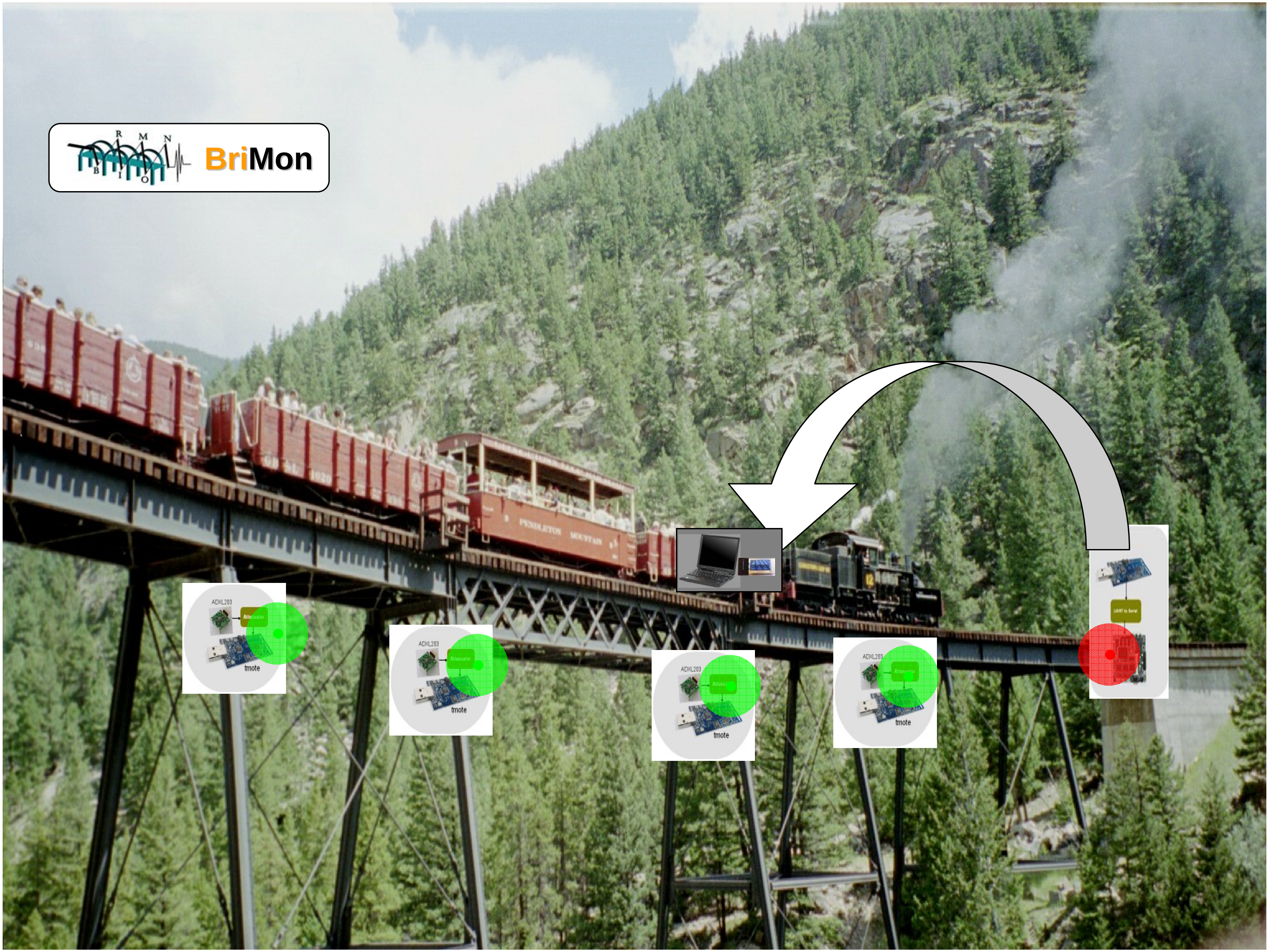
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Hardware Module Details

Software

BriMon

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Modules (Hardware)

- Messaging and transporter module
  - Laptop or Soekris attached to a sector antenna.
  - Beacons the frontier node
  - Data retrieval from data aggregator using https over TCP
- Frontier node
  - Detects train arrival using Wake-on-WLAN
  - Notifies the base node at data aggregator

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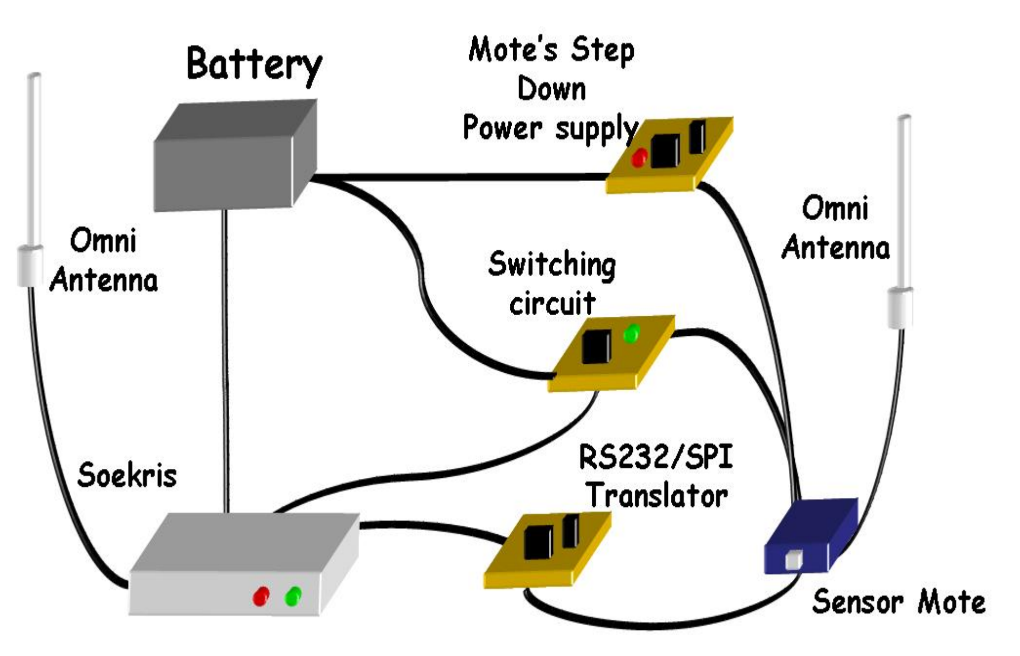
Modules (Hardware)

- Data aggregator node
  - Both 802.11 and 802.15.4 radios
  - Mote acts as root node for sensors deployed on bridge
  - Soekris for higher bandwidth data transfer via 802.11 and storage.
  - Initiates routing and keeps node time-synchronized



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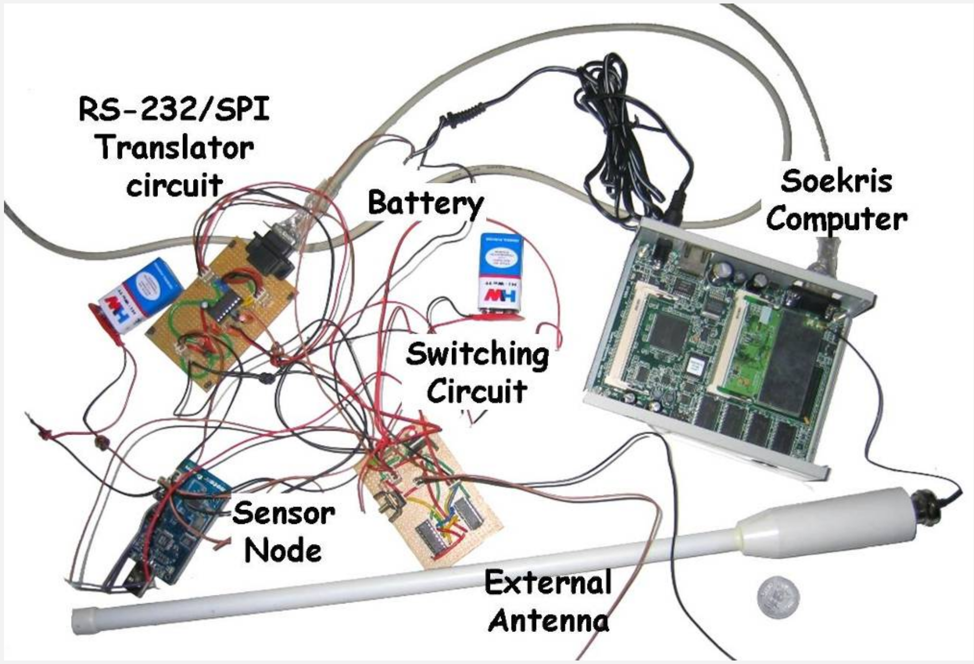

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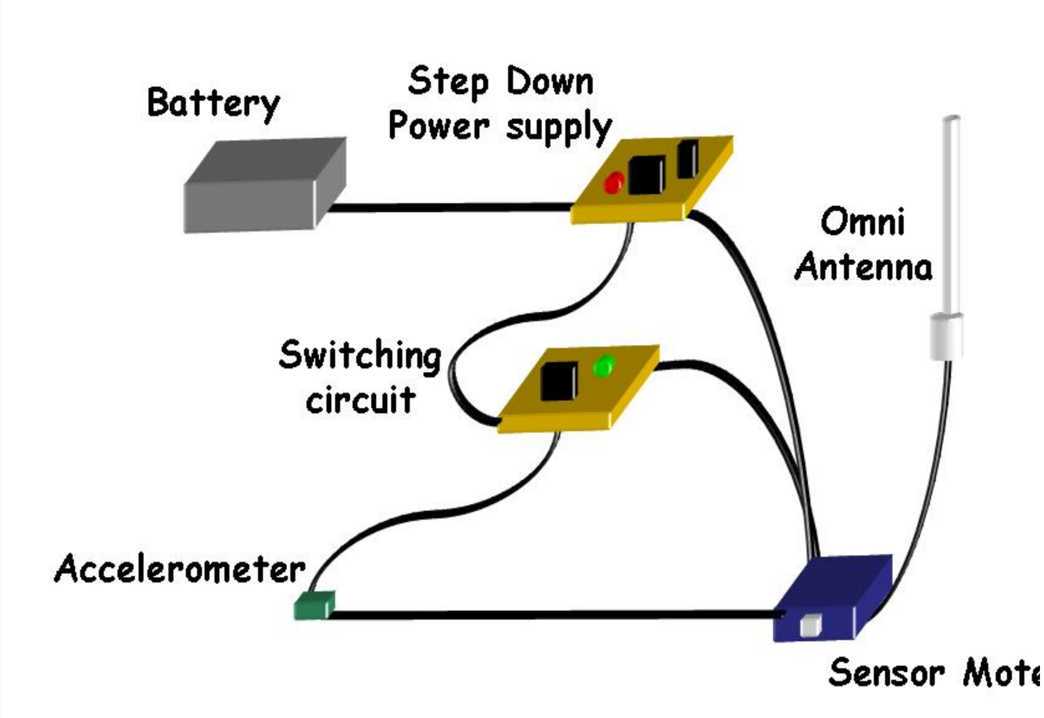
Modules (Hardware)

- Data Collector node
  - Accelerometer to collect data
  - Duty cycling to save power
  - Time-stamped data logged and transported reliably
  - Is slave to root node



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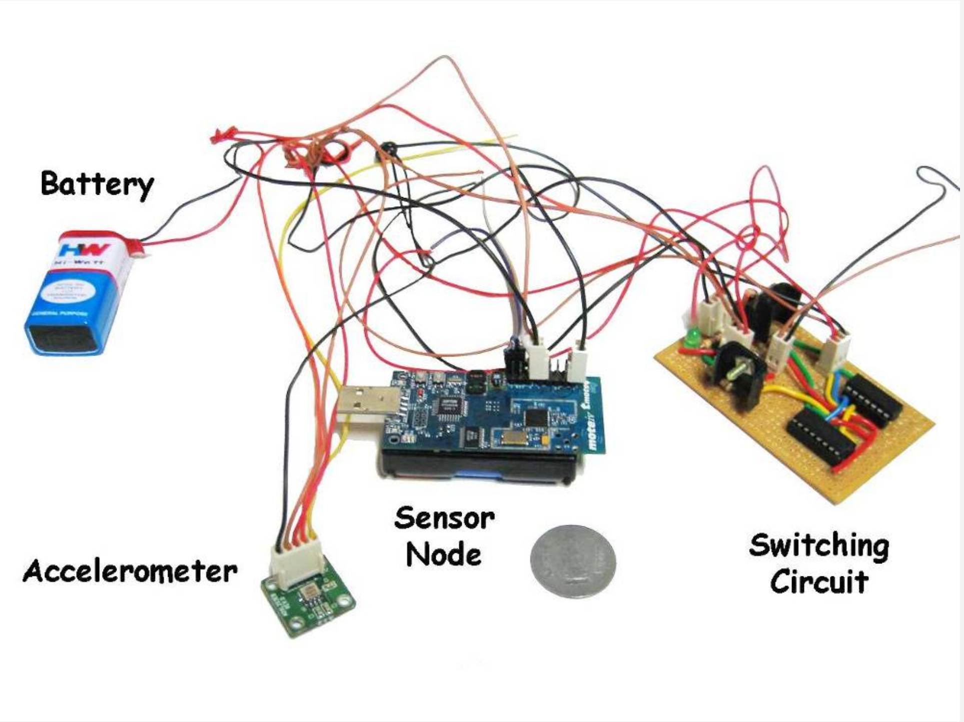

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Modules (Software)

- Flooding Time Synchronization Protocol (**FTSP**)
  - Uses flooding to disseminate timing information.
  - Packet time stamped at transmission and reception
  - Maintains a table of most recent synchronization points (global-local time pair)
  - Skew compensation using least square linear regression on offset vs. local time

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Modules (Software)

- Two components for time synchronization error
  - Offset
  - Skew
- We get

$$Offset = Globaltime - Localtime$$

$$Skew = \frac{Offset - Offset_{Average}}{Localtime - Localtime_{Average}}$$

$$Offset = Offset_{Average} + Skew * (Localtime - Localtime_{Average})$$

$$Globaltime = Localtime + Offset_{Average} + Skew * (Localtime - Localtime_{Average})$$

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Modules (Software)

- Original implementation
  - Flushes the synchronization point table in case it receives an invalid packet
  - Current implementation randomly injects invalid packets at any node (missing local time)
  - Low network stability

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Modules (Software)

- Refinement
  - We do not flush the table but reject packets with very high or very low values.
  - Higher errors but more stable network
  - Applicable for our scenario (as time-synchronization requirements are in ms range)

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Modules (Software)

- Event Detection
  - We detect a train carrying the necessary messaging and transporter module.
  - The same train is used for source of vibration as well as data transportation.
  - Train detected using *Wake-on-WLAN*

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Component details

[Discussion](#)

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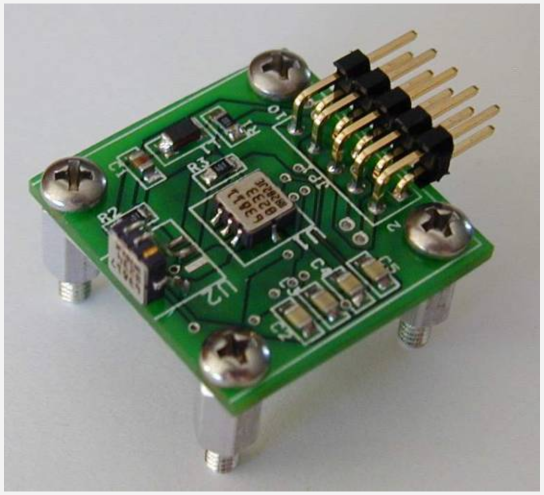
Components (Hardware)

- Accelerometer (ADXL 203)
  - Dual axis MEMS
  - ±1.7g range with 1000mv/g resolution
  - Low power (700µA @ 5V)
  - 3-5 V working range
  - Relative low noise (110 $\mu g/Hz^{1/2}$)



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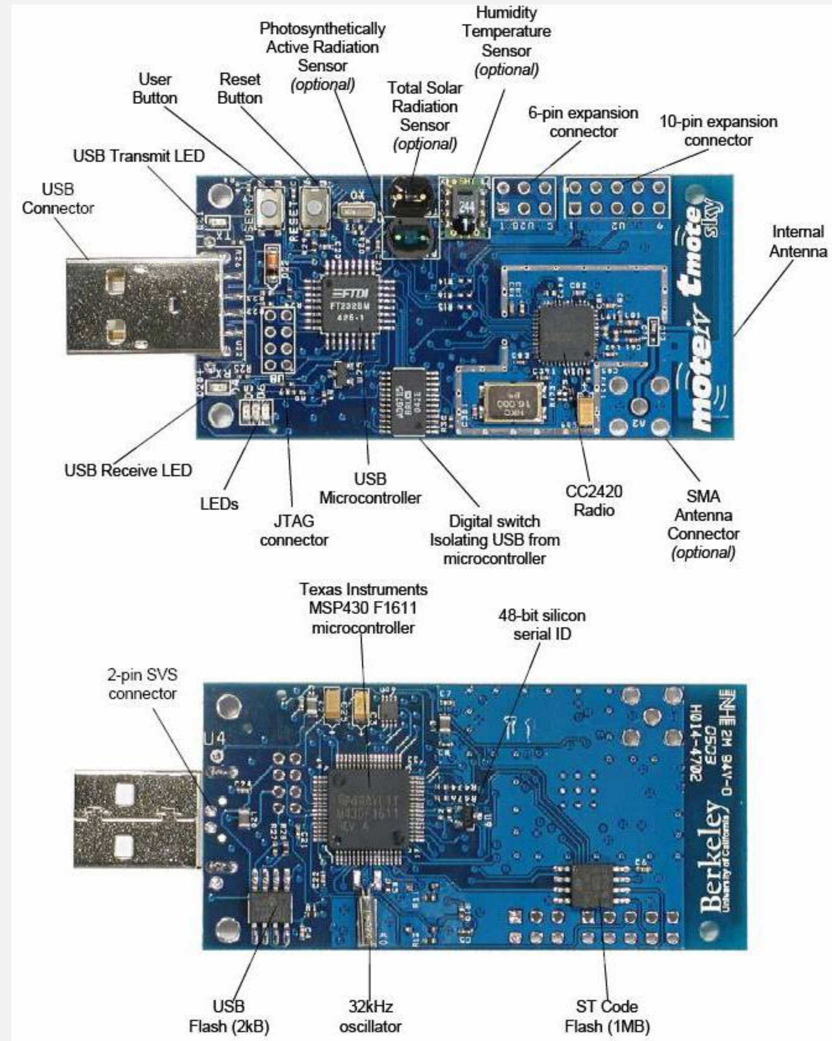
Components (Hardware)

- Tmote-sky
  - Low power 16 bit micro controller
  - 10KB RAM and 48KB program flash
  - 1 MB data flash
  - 2.4 GHz 802.15.4 compliant radio
  - 12 bit ADC with multiple protocol interfaces



Components (Hardware)

- Soekris
  - Smallish linux kernel
  - Variable power supply options (5-56V)
  - 1-2 WiFi cards
  - 128-512 MB data memory.

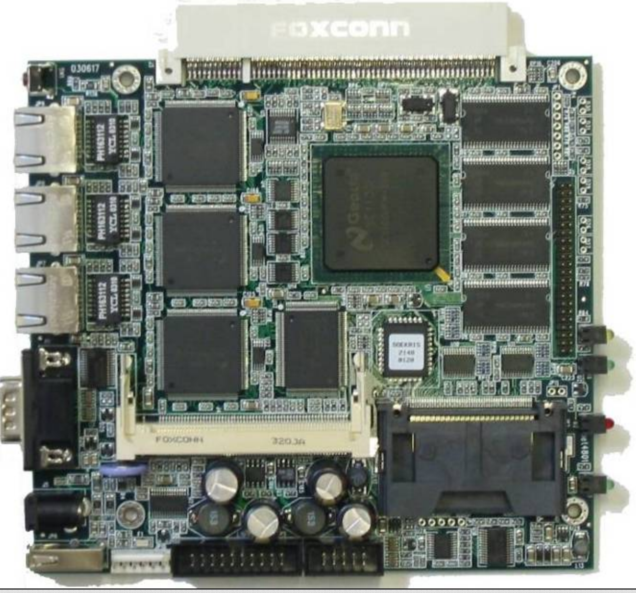


*Image source: Internet search

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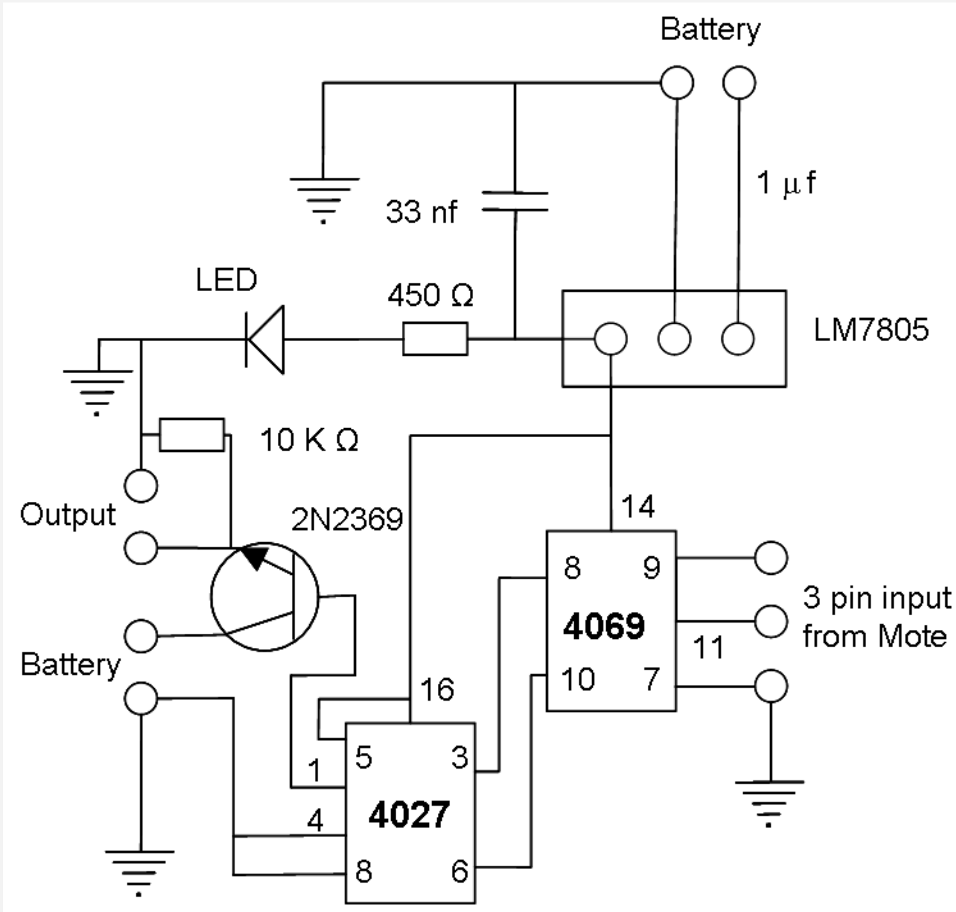
Components (Hardware)

- Switching Circuit
  - Based on high current power transistor TIP31C
  - Latches state allowing node to sleep
  - Voltage range 0-100V



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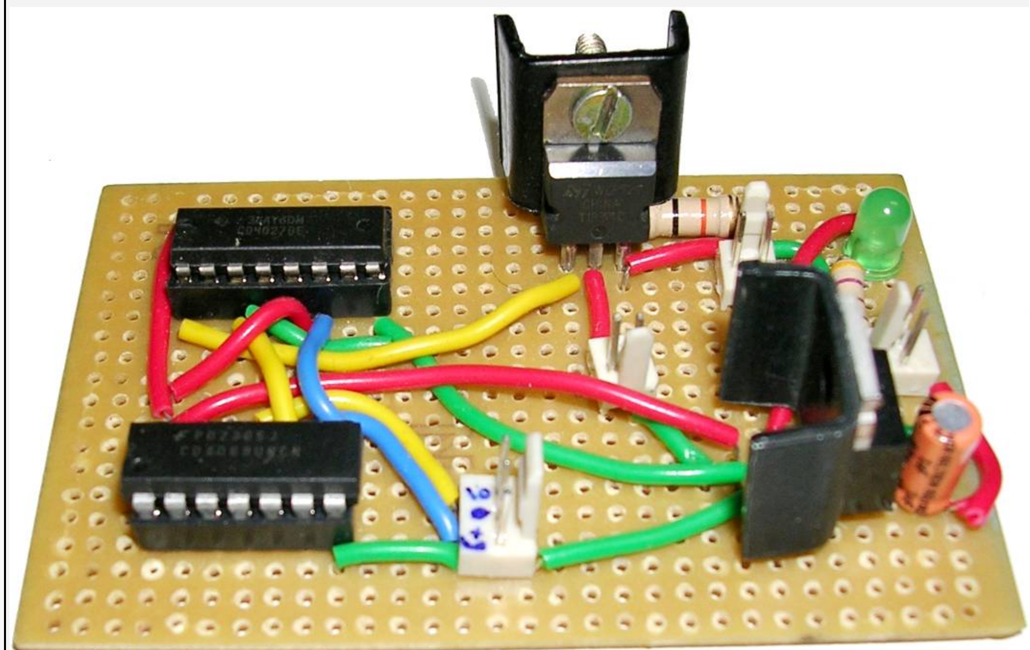

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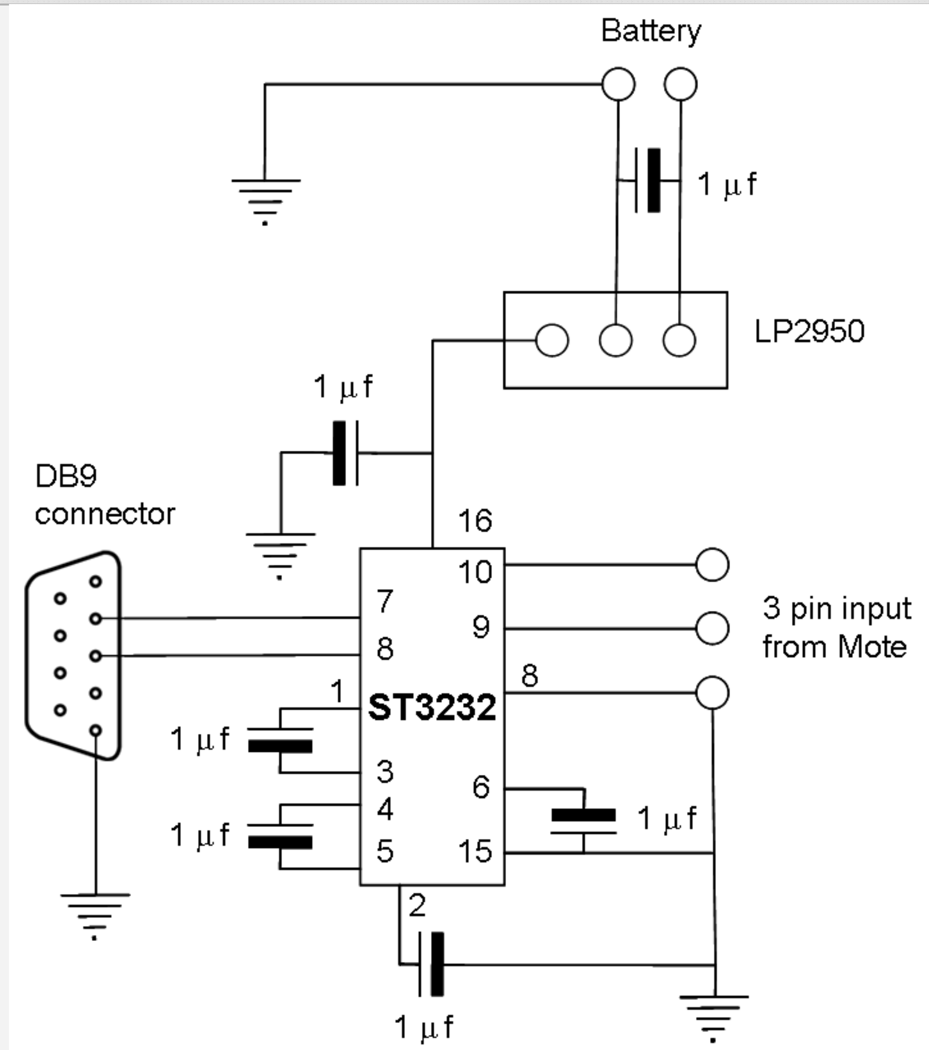
Components (Hardware)

- RS232-SPI interface
  - Uses ST3232
  - LP2950 low dropout voltage regulator for accurate 3.3V operations



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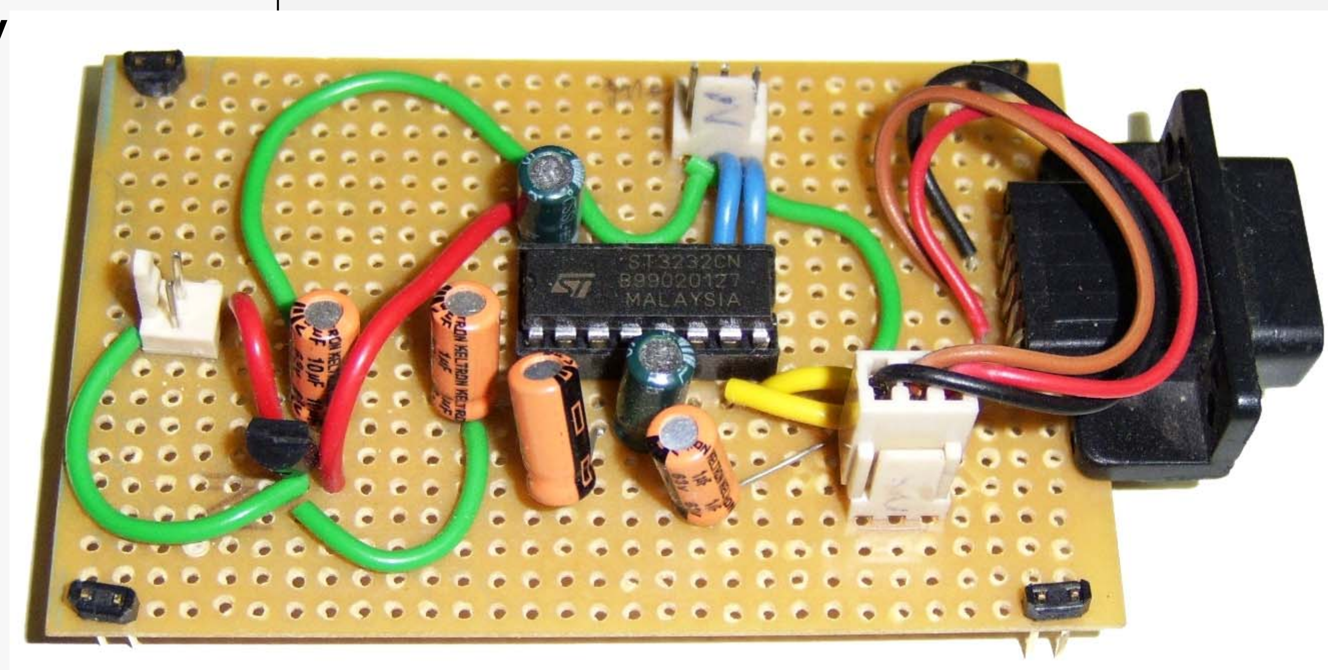
  - Uses ST3232
  - LP2950 low dropout voltage regulator for accurate 3.3V operations



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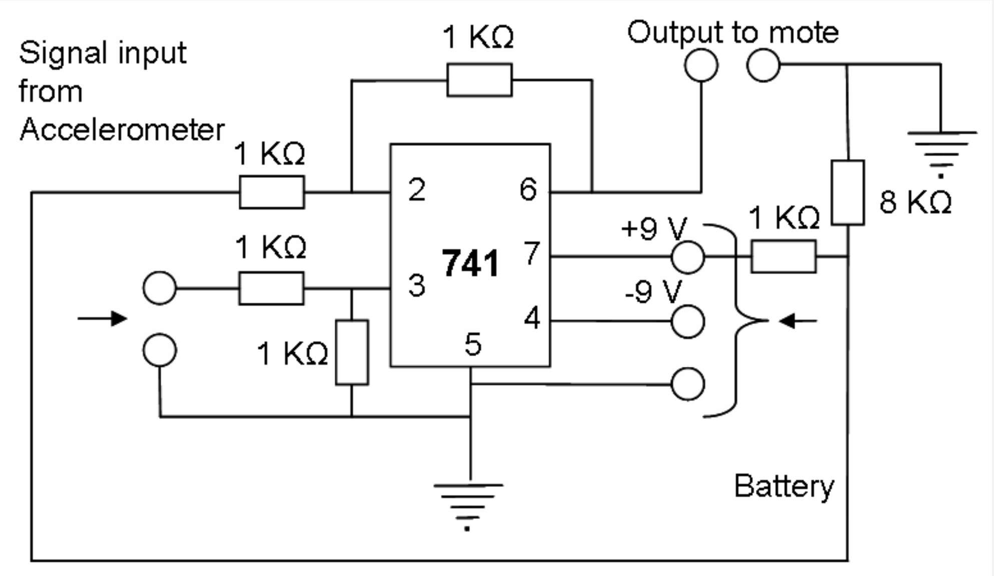
Components (Hardware)

- Attenuator circuit
  - Differential amplifier based design
  - Used to shift voltage range
  - Can be used for amplification/attenuation



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Components (Hardware)

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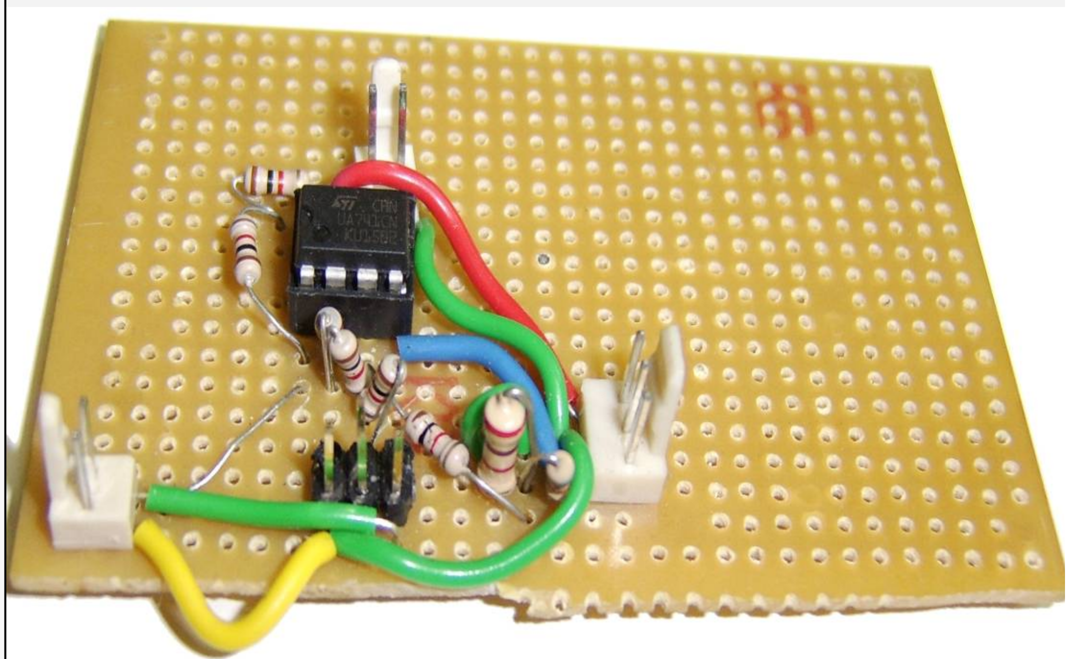

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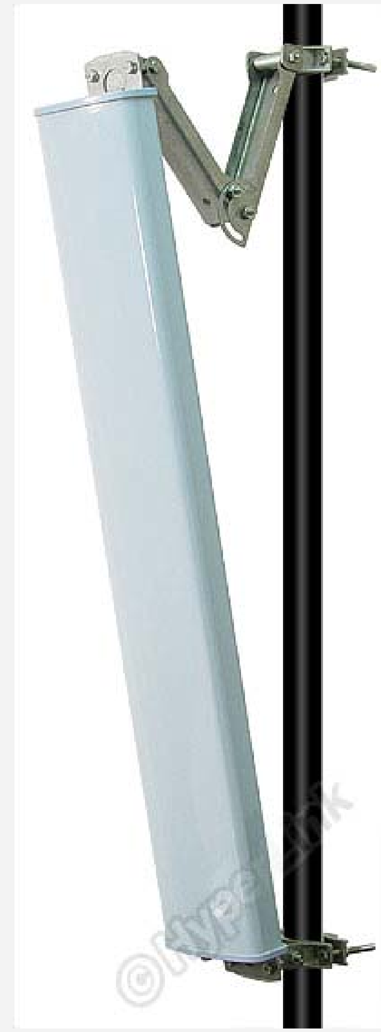
Components (Hardware)

- Antennae
  - 3dBi internal omni-directional antenna
  - 8dBi external omni-directional antenna
  - 17dBi external sector antenna



Is 12 bit ADC sufficient?

- Domain requires resolution of 0.01 g
- Tmote's 12 bit ADC used
  - Reference voltage 2.5 V
  - Range 0-2.5 V
- Accelerometer used at 3V
  - ± 1.7g range
  - 560 mV/g resolution
  - 0g voltage $V_{cc}/2$ i.e. 1.5 V

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Is 12 bit ADC sufficient?

- Output from accelerometer
  - $1.5 \pm (1.7 \times 0.56) = 0.548 - 2.452$
- 0.01g will result in $0.01 \times 560 = 5.6$ mV change in output
- Total number of steps in 12 bit ADC = 2^{12} = 4096
  - Change per step = 2.5/4096 = 0.6mV
  - 0.01g change in accelerometer output will give ≈ 9 steps change in ADC

Why use 802.11?

- Data getting generated per node = 1440Kb
- Maximum achievable rates ≈ 31.6Kbps
  - 46 s to transfer data without compression from one node
- Total data generated for 9 node deployment 12.96 Mb
  - Requires 410s of communication contact on 802.15.4 for data transfer across train
- Will take only 3.5s for transfer via 802.11 at 3.7 Mbps

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Long Maintenance

- 10% duty cycle for sensor nodes
- 0.1% duty cycle for Soekris
- Using D size alkaline batteries offering 11AH of power achievable life ≈ 2200 Hrs or 3 months
  - Assumes working range from 3.2 to 1.8V with average supply at 2.4V
  - Tmote's flash work only above 2.7V

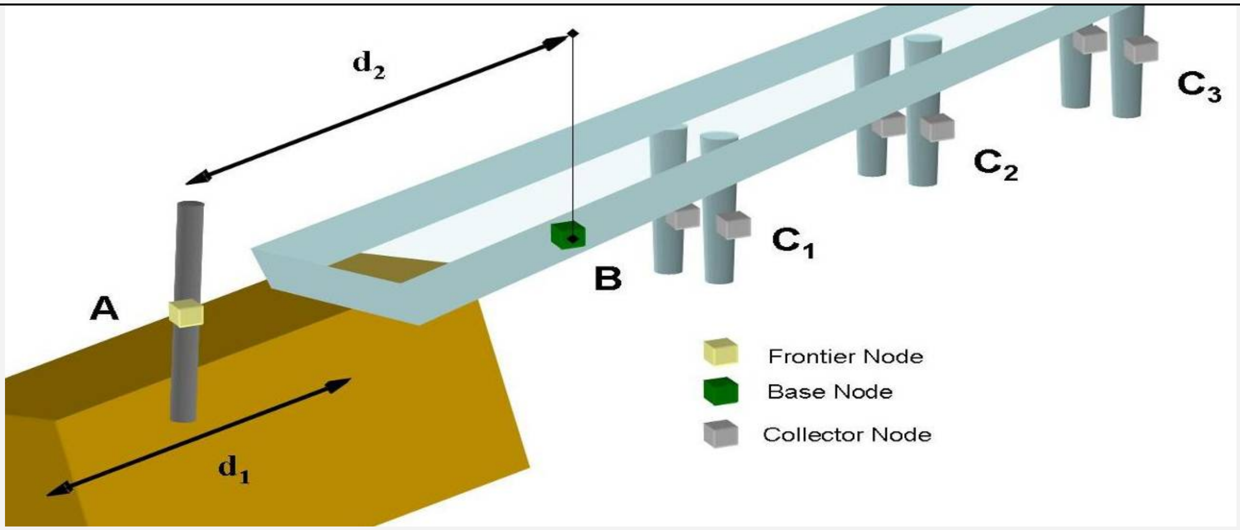
Low cost

- Original equipment cost for 9 node
  - $75,000 ($8,000 per node)
- Our approach
  - $455 (aggregator)
  - $165 (collector)
  - $161 (frontier)
  - $420-$660 (M & T)
- Total cost for 9 node
  - $2491
- > **96%** cost savings

	Cost (in $)	Used in
Sensor Node	78	FN, DA and DC
ADXL103 Accelerometer	8	DC
HyperLink 8 dbi omni directional antenna	50	FN, DA, DC, and M&T
HyperLink 17 dbi 120° directional antenna	160	FN, and M&T
D size alkaline Batteries	0.7	FN, DA, and DC
Soekris net4826 single board computer	190	DA
Mini PCI 802.11 WiFi card	60	DA
Laptop with 802.11	500	M&T
Auxiliary circuits	< 10	DA, and DC

Frontier node location

- v_1 = train speed, d_1 = range of the radio at ***A*** (frontier node) then, $t_1 = d_1/v_1$ = time spent by train in ***A***'s range
- d_2 = distance between frontier node and data aggregator node ***B***.



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Frontier node location

- Assuming the worst case when T_1 = sleep time for node at ***A***, then time taken by train to cover remaining distance when it gets detected at ***A*** is

$$t_2 = 1/v_1 * (d_2 - d_{1/2})$$

  - This is the time for Soekris at ***B*** to boot up and nodes at C_1, C_2 and C_3 to wake up.

Frontier node location

- If T_2 = sleep cycle time for mote at B and T_3 = boot up time for Soekris then

$$T_3 + T_2 \leq t_2$$

- Assuming T_4 = sleep cycle time for data collector motes = T_2 we get

$$d_2 \geq v_1(T_3 + T_2) + d_1 / 2$$

- Plugging values of v_1 = 36Km/h, T_3 = 45s, T_2 = T_3 = 10s and d_1 = 150m we get d_2 = 625m.
- For v_1 = 72 Km/h d_2 = 1275m

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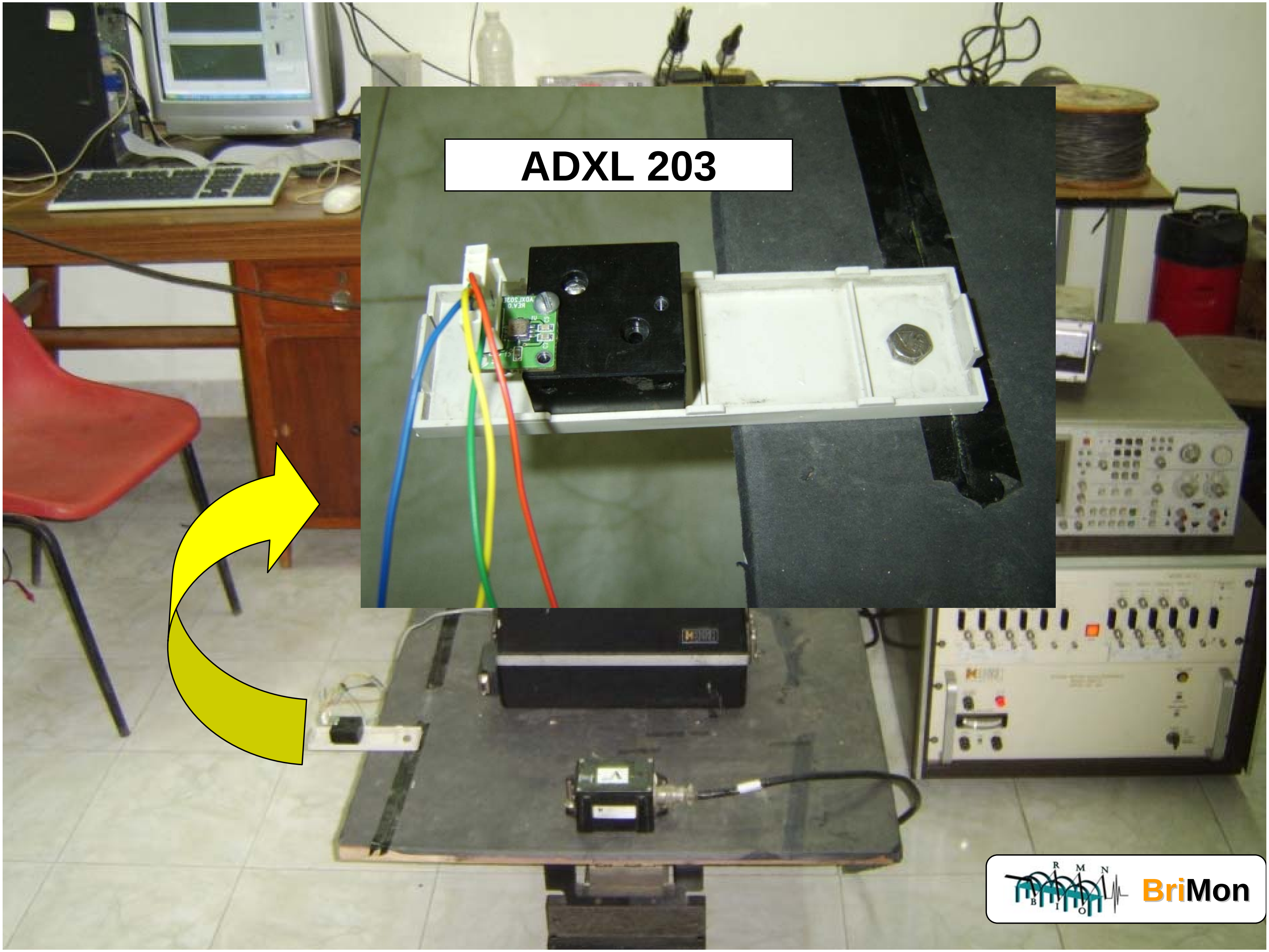
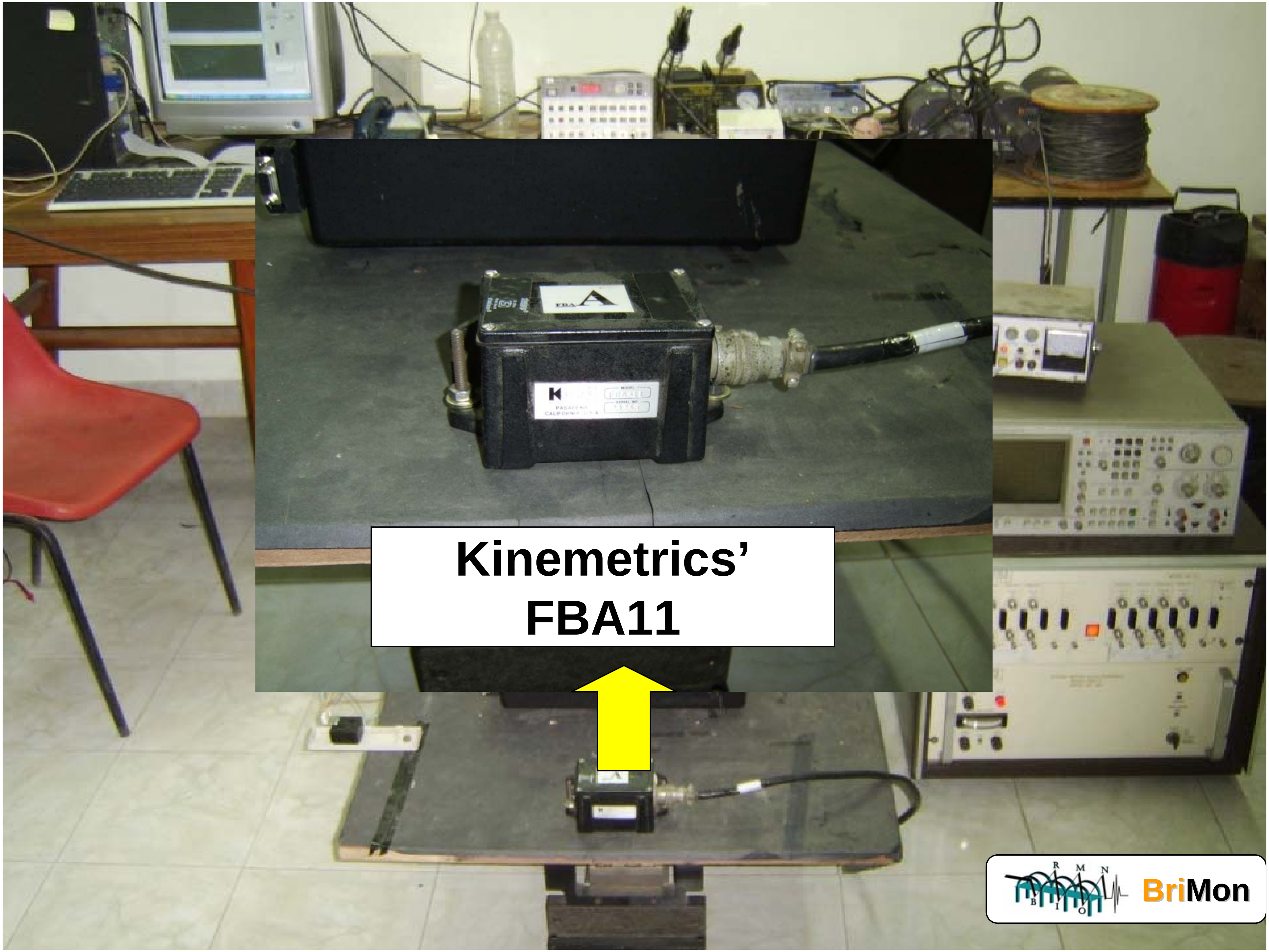
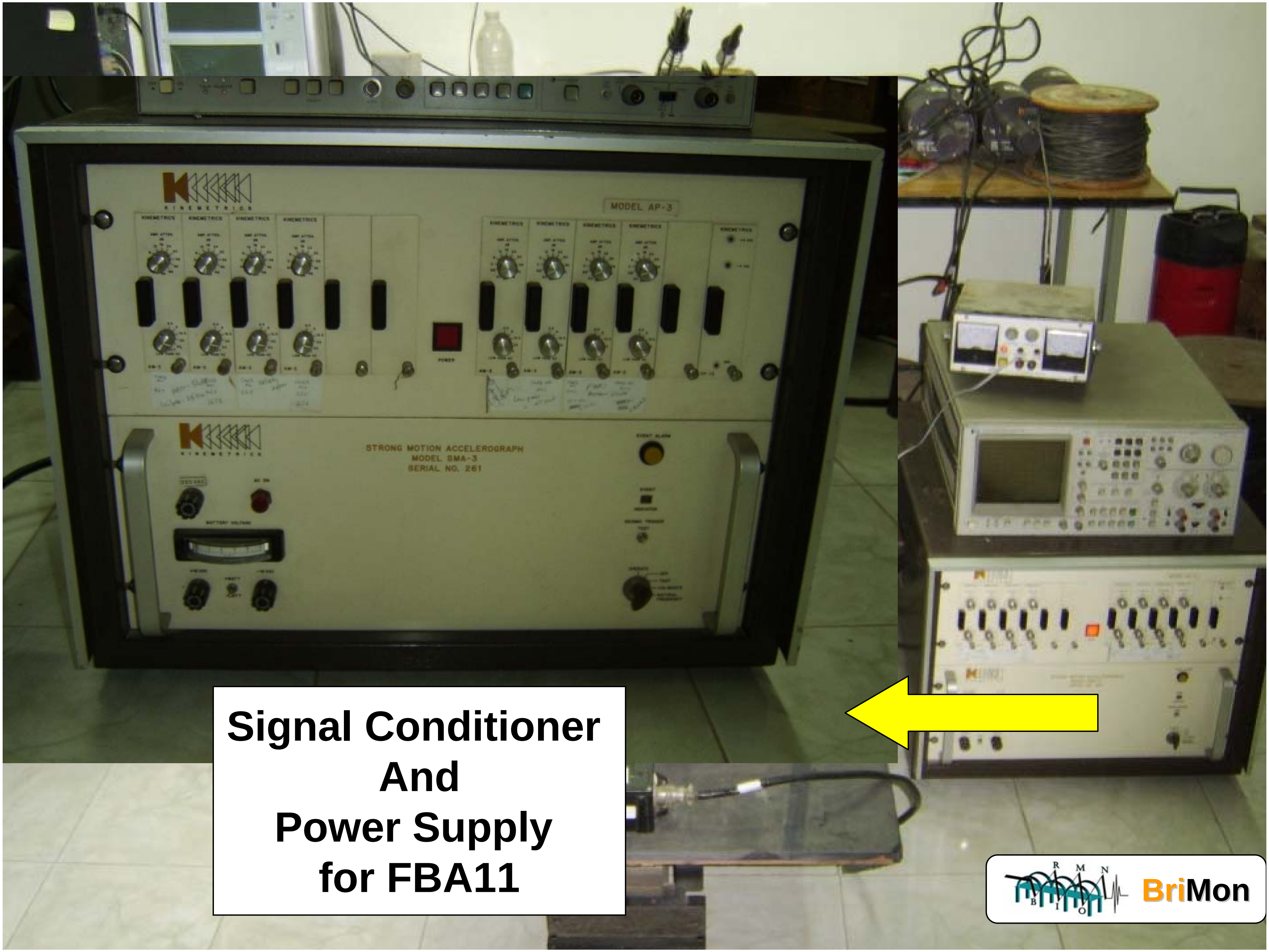
Accelerometer Comparison

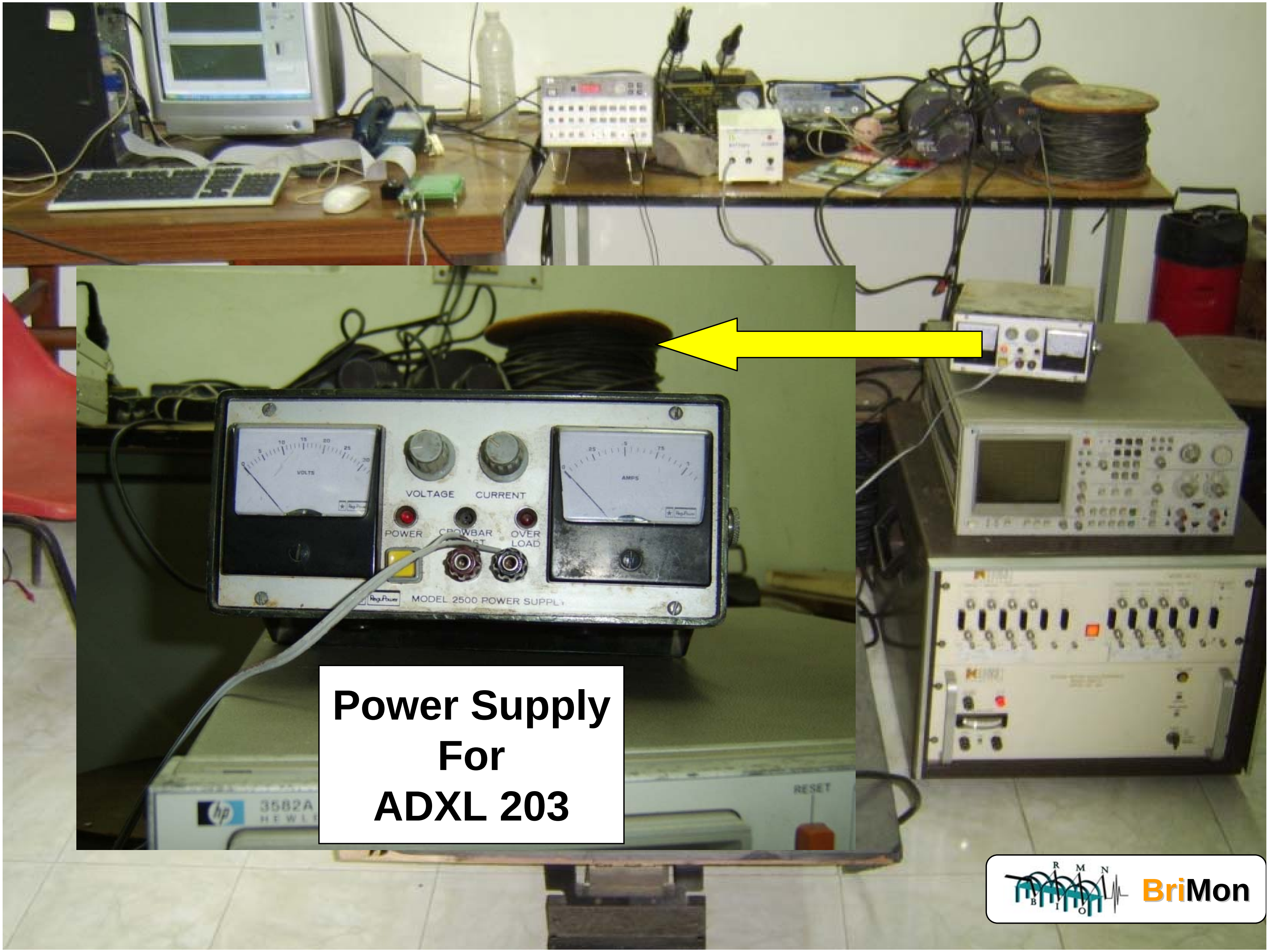
- Current systems use bulky FBA (Forced Balance Accelerometers)
- Replacement requires validation whether same results are available or not.
- Experimental setup (Structure's lab, IIT Kanpur)


ADXL 203
BriMon

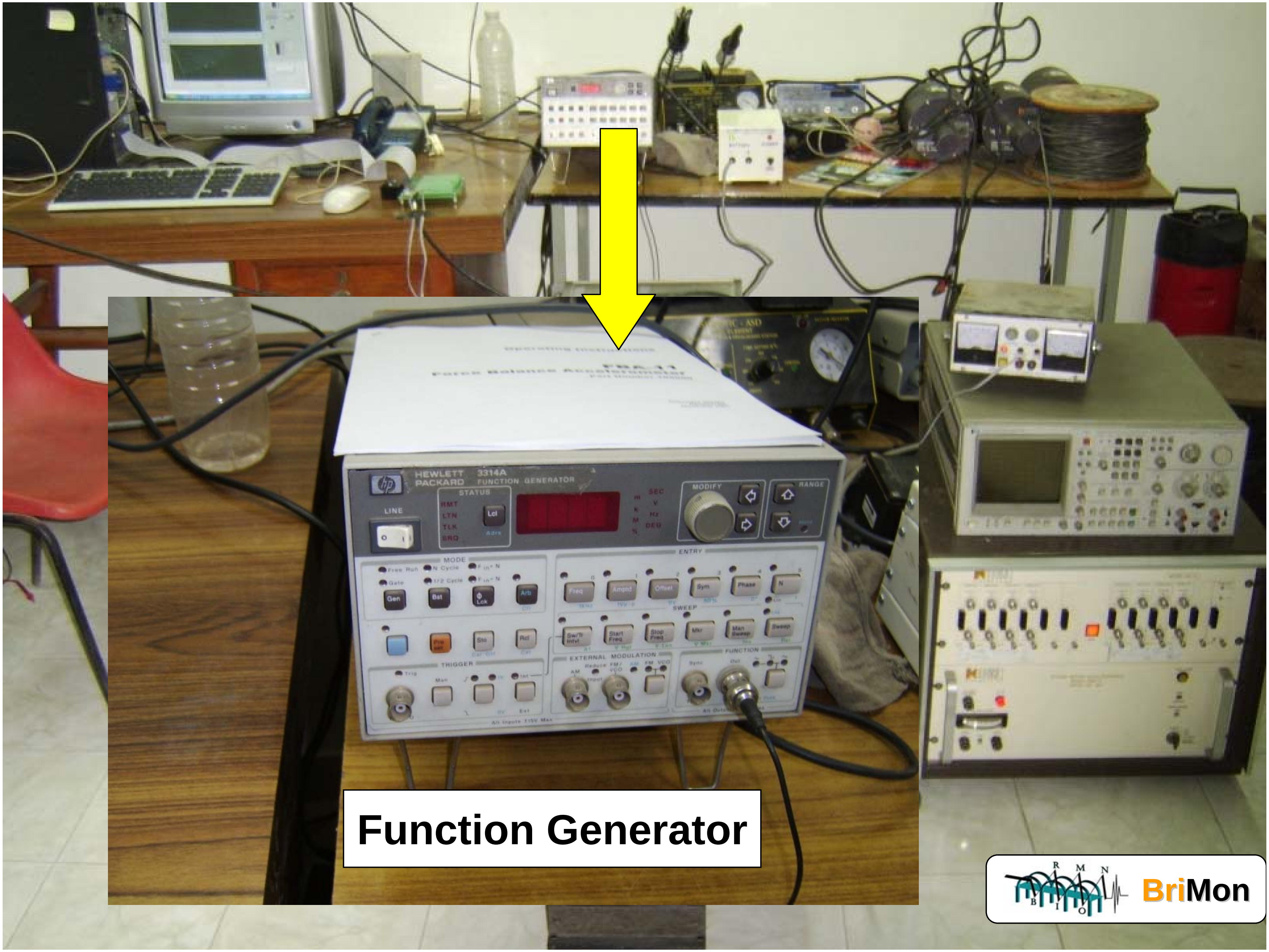

Kinemetrics' FBA11
BriMon



**Signal Conditioner
And
Power Supply
for FBA11**

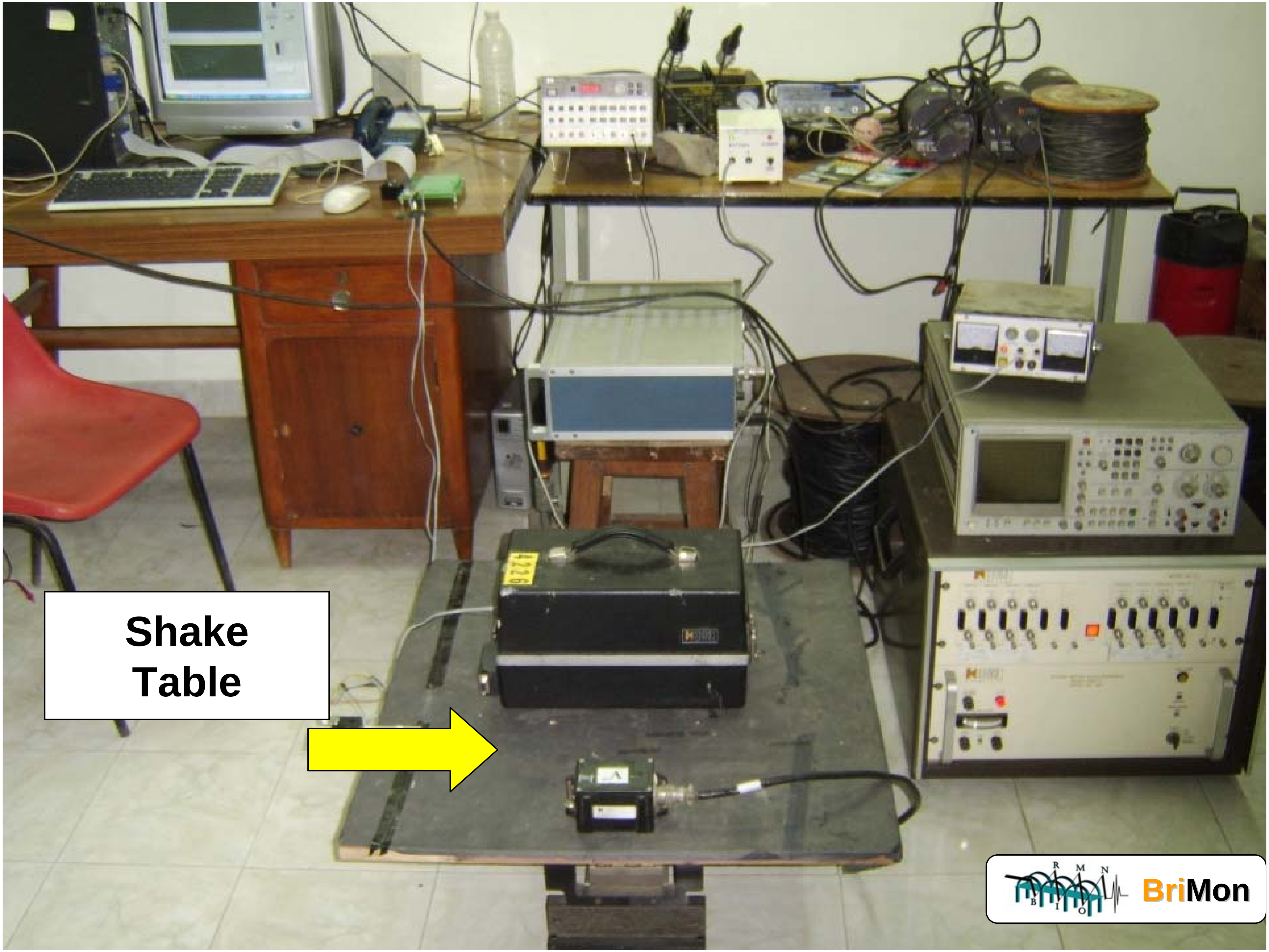

Power Supply
For
ADXL 203
VOLTAGE
CURRENT
POWER
OVER
LOAD
VOLTS
AMPS
MODEL 2500 POWER SUPPLY
3582A
RESET

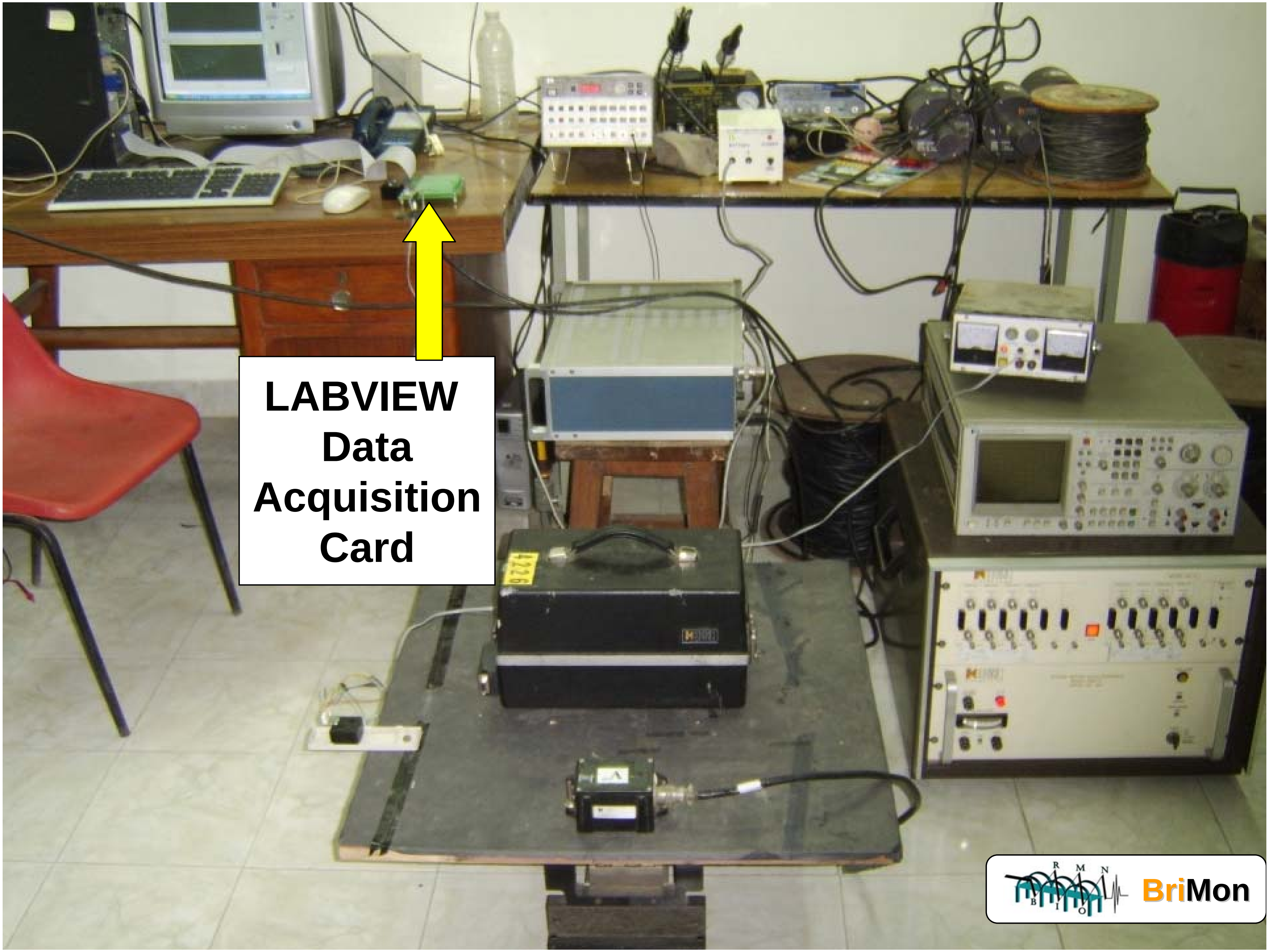
BriMon

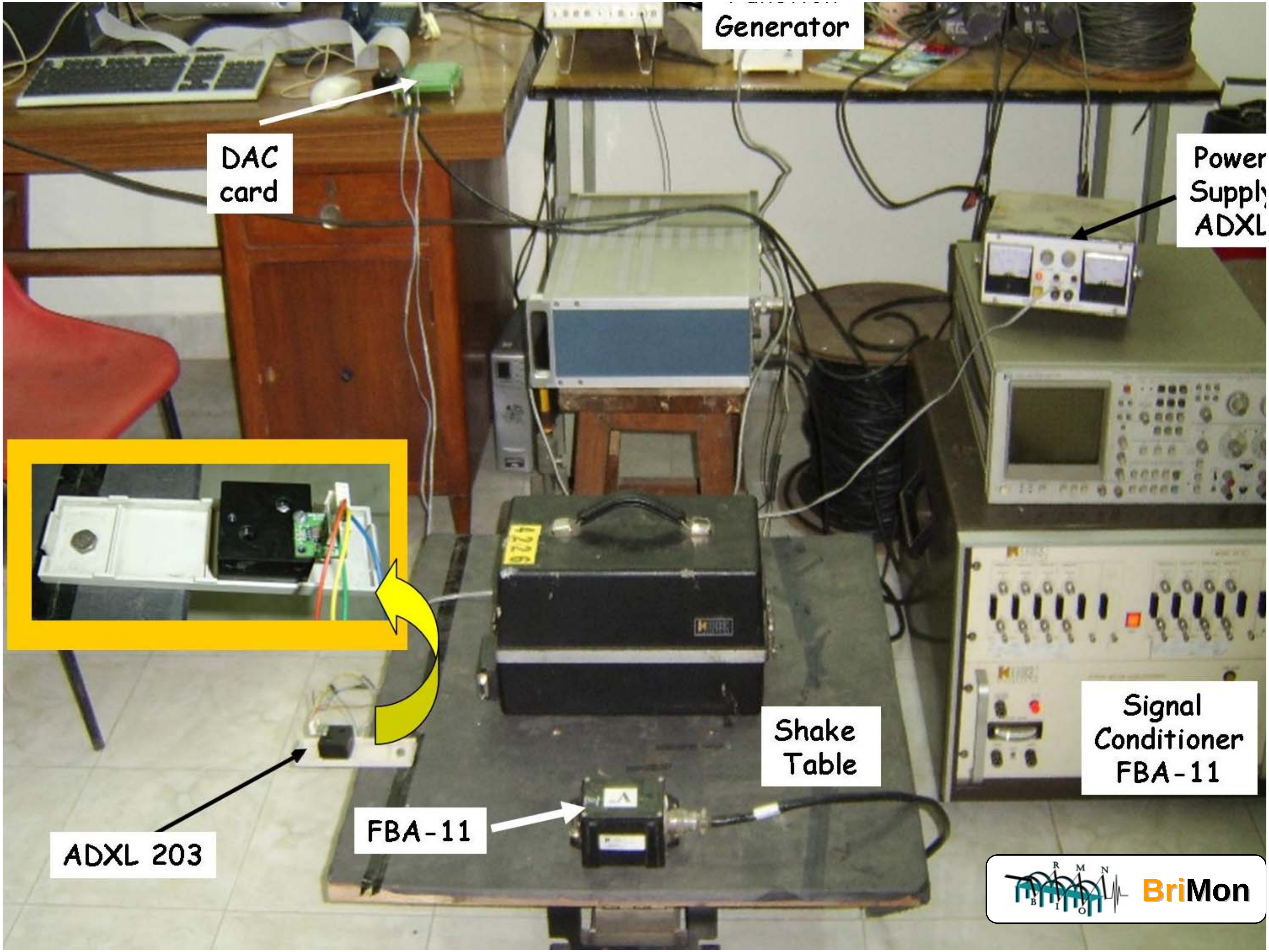


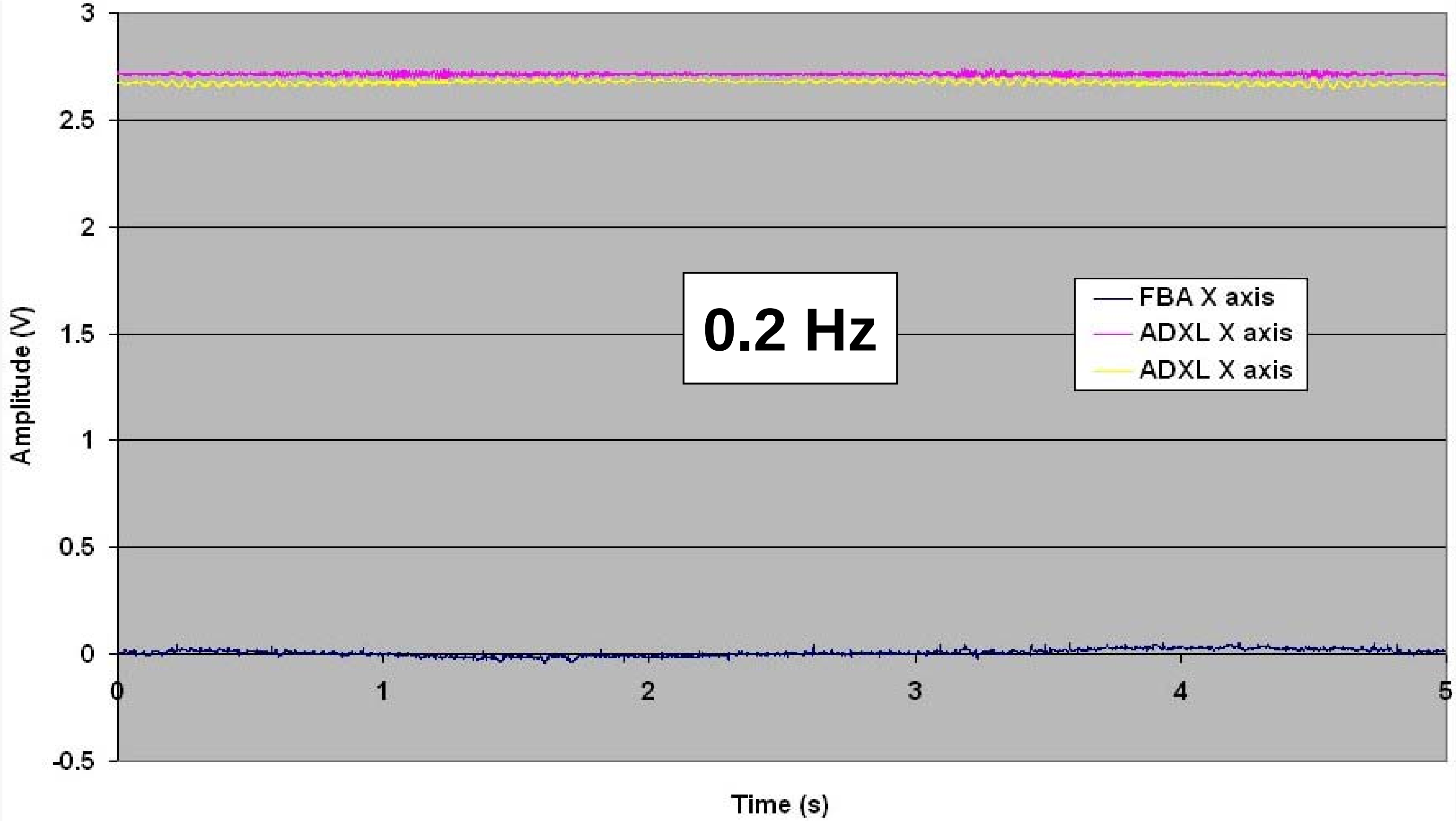
Function Generator

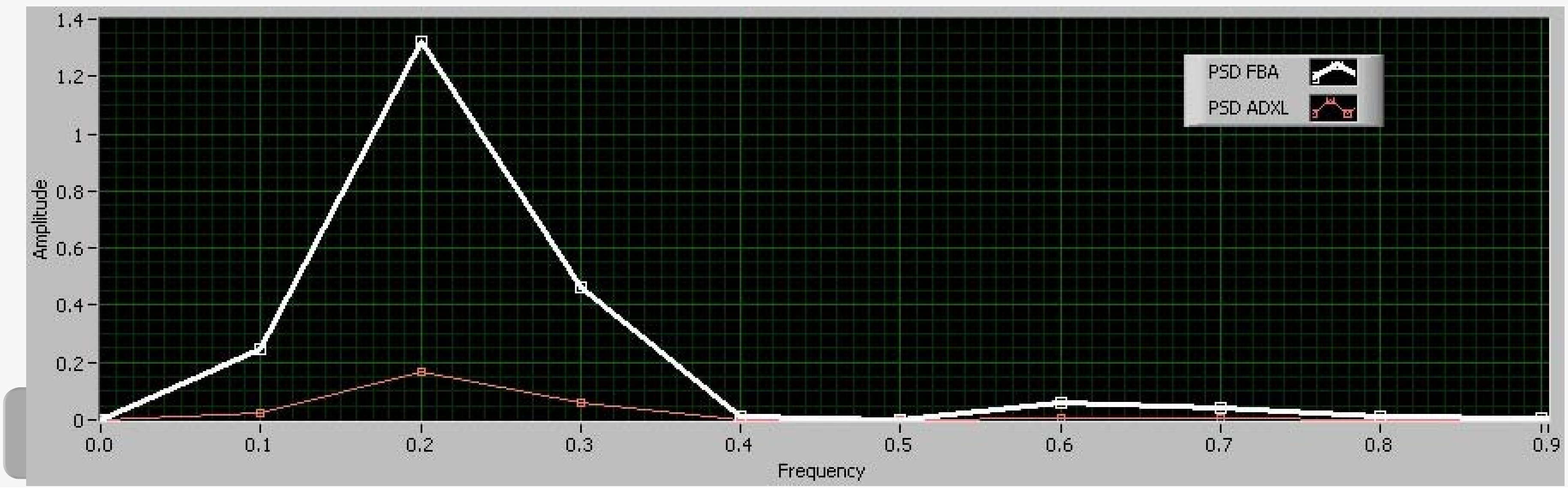
BriMon

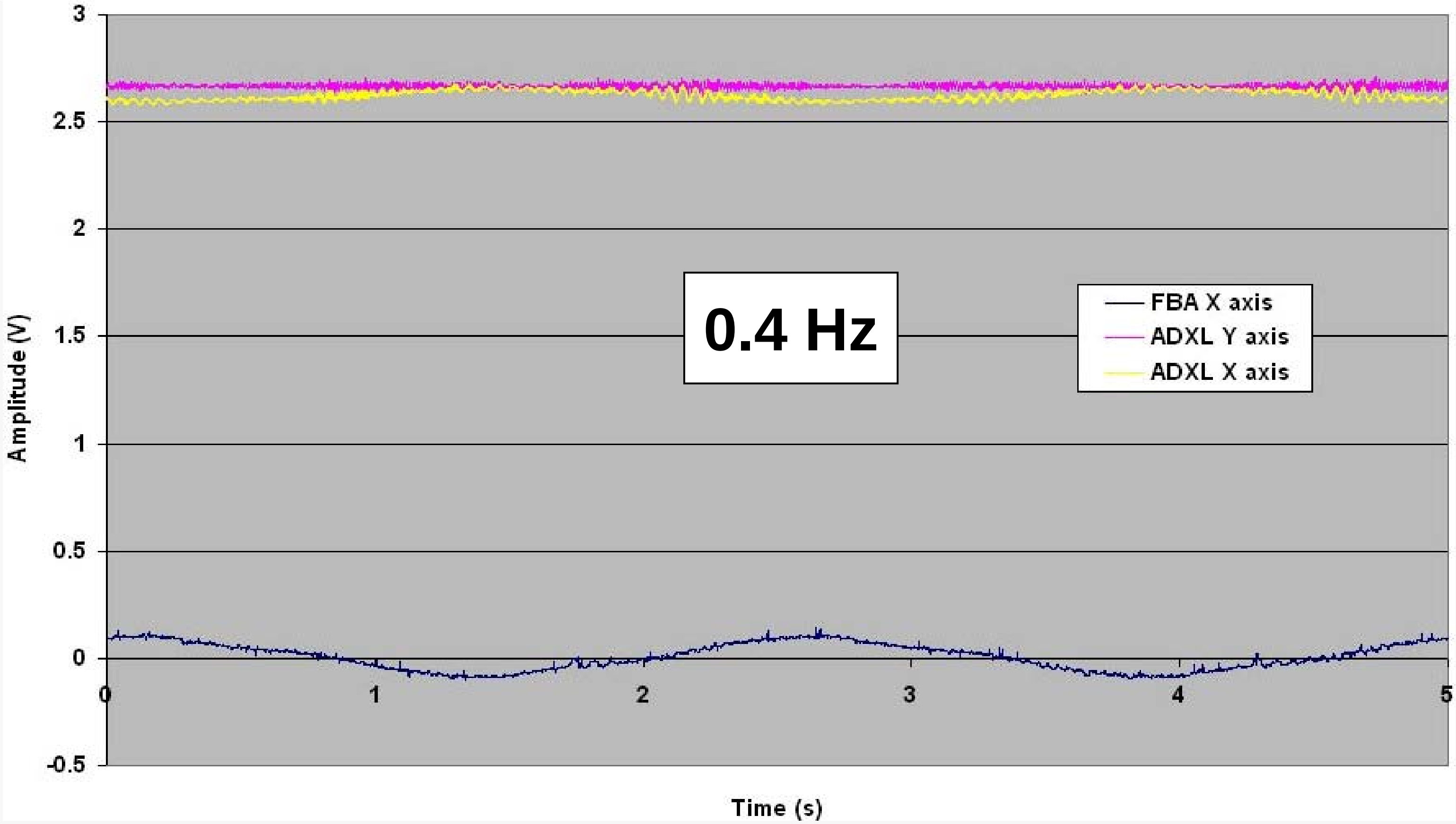

Shake
Table
BriMon

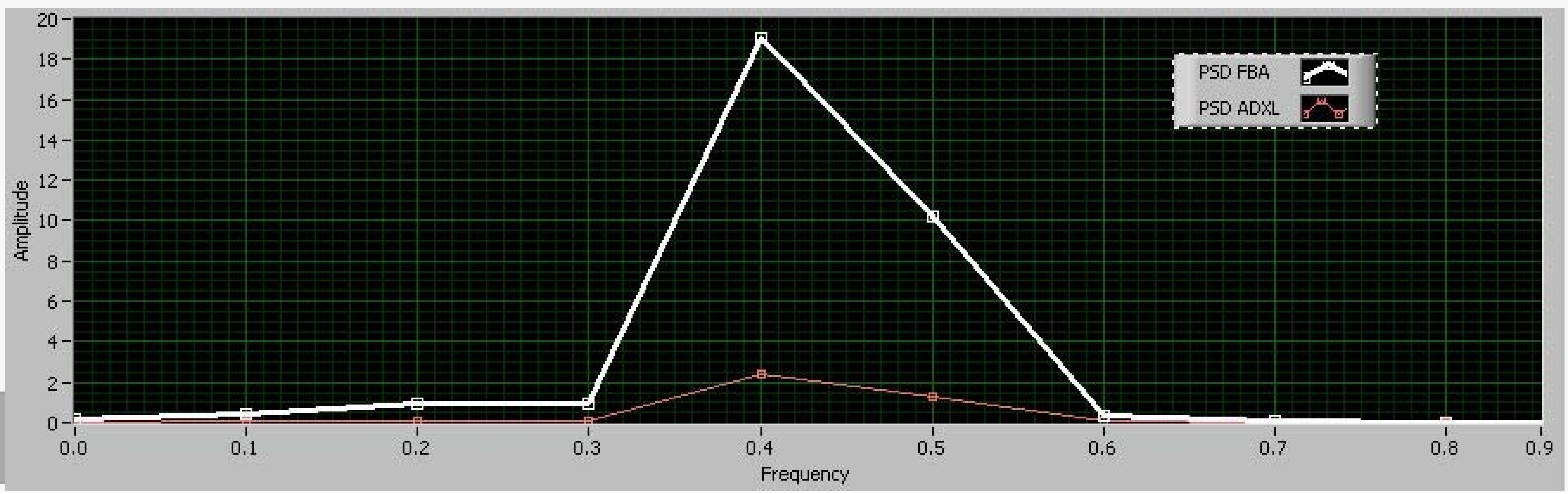

LABVIEW
Data
Acquisition
Card
BriMon

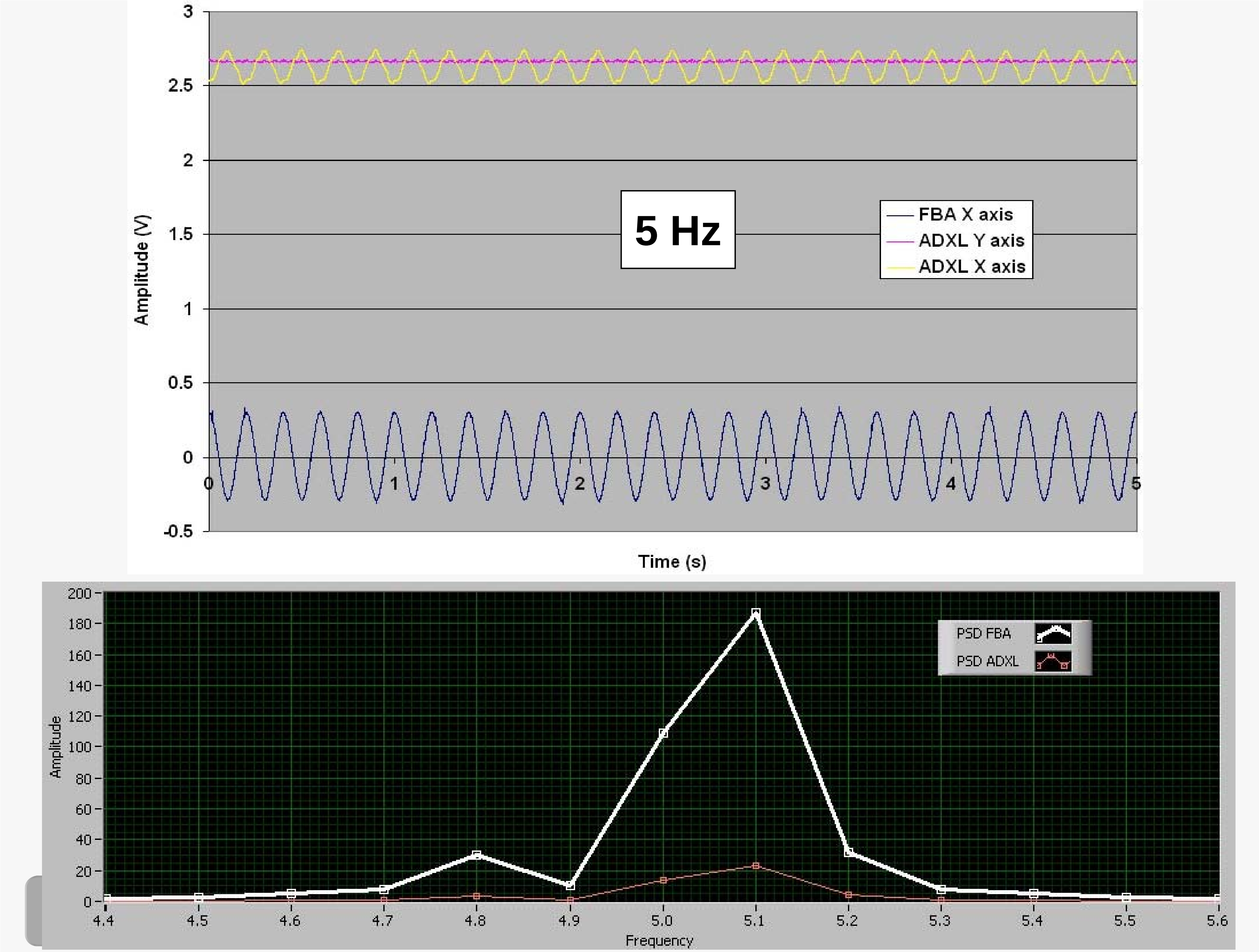

Generator
DAC card
Power Supply ADXL
Shake Table
Signal Conditioner FBA-11
FBA-11
ADXL 203
BriMon


0.2 Hz
FBA X axis
ADXL X axis
ADXL X axis
Amplitude (V)
Time (s)
3
2.5
2
1.5
1
0.5
0
-0.5
0
1
2
3
4
5

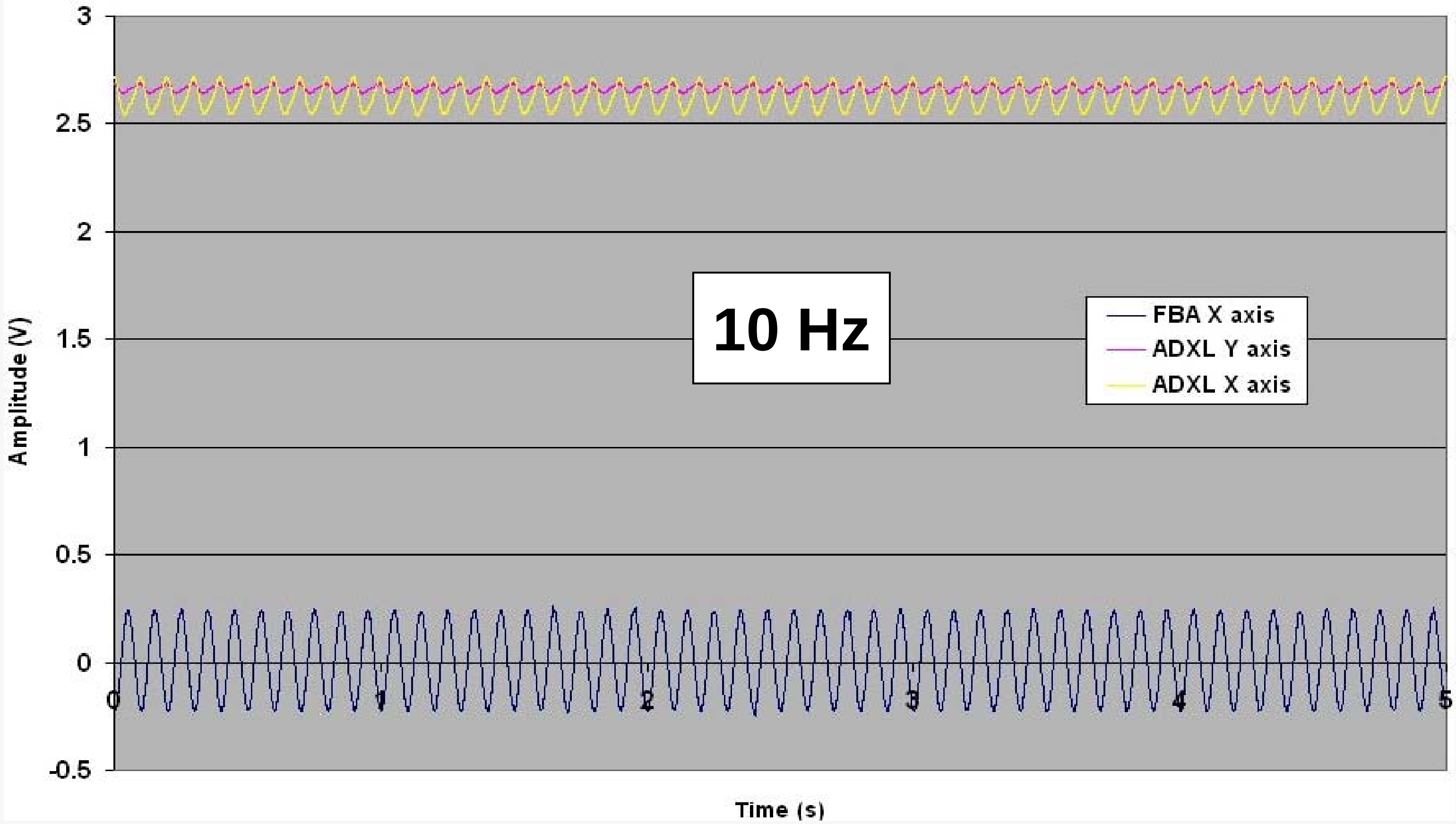

PSD FBA
PSD ADXL
Amplitude
Frequency
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9


0.4 Hz
FBA X axis
ADXL Y axis
ADXL X axis
Amplitude (V)
Time (s)
3
2.5
2
1.5
1
0.5
0
-0.5
0
1
2
3
4
5

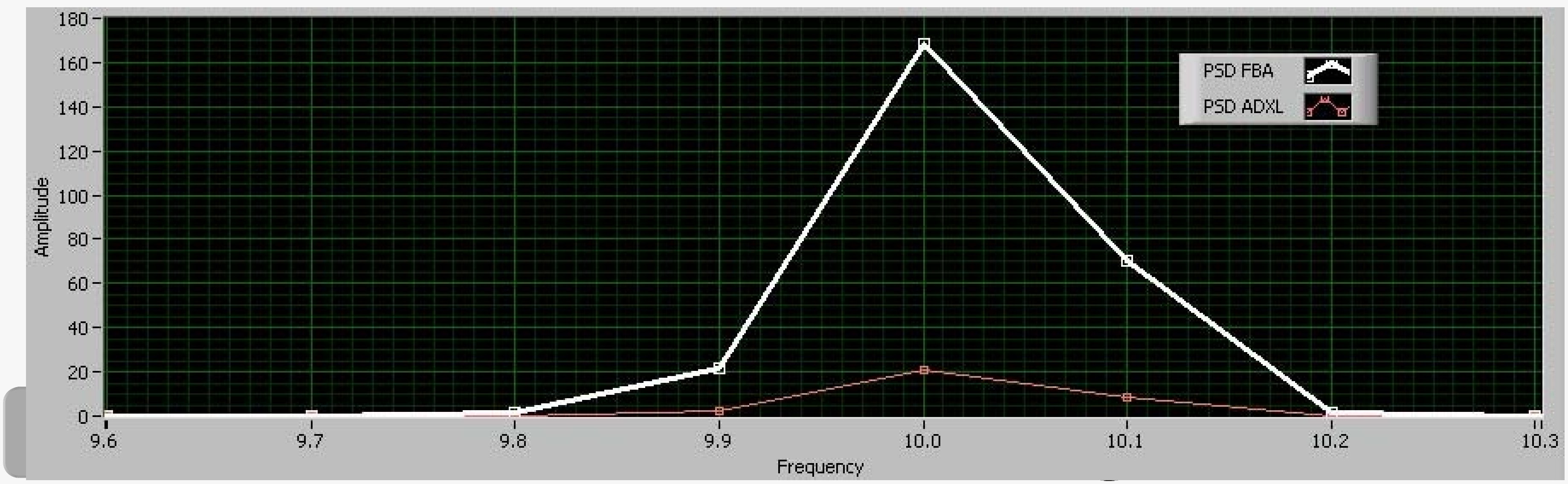

PSD FBA
PSD ADXL
Amplitude
Frequency
20
18
16
14
12
10
8
6
4
2
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9



5 Hz
FBA X axis
ADXL Y axis
ADXL X axis
Amplitude (V)
Time (s)
PSD FBA
PSD ADXL
Amplitude
Frequency



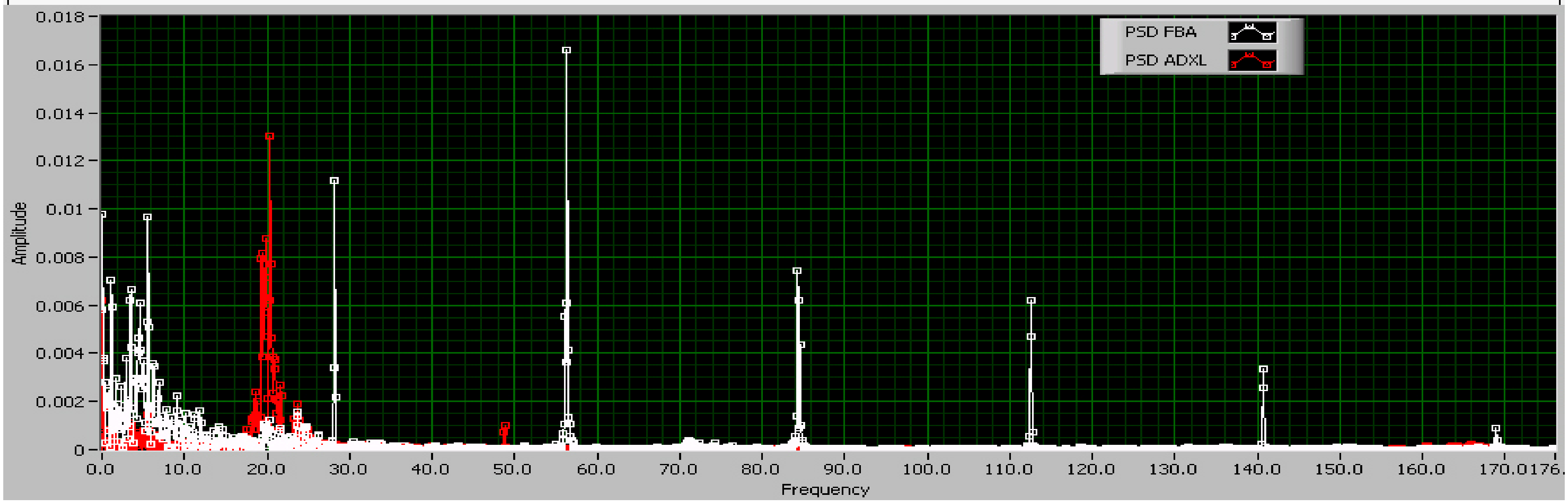
10 Hz
FBA X axis
ADXL Y axis
ADXL X axis
Amplitude (V)
Time (s)
3
2.5
2
1.5
1
0.5
0
-0.5
0
1
2
3
4
5



PSD FBA
PSD ADXL
Amplitude
Frequency
180
160
140
120
100
80
60
40
20
0
9.6
9.7
9.8
9.9
10.0
10.1
10.2
10.3

Accelerometer Comparison

- Both accelerometers effective for frequencies ≥ 0.2 Hz
- At 0.1 Hz both accelerometers fail to register correct frequency (inadequate acceleration)
- Using filters gives better results but



802.11 detection using motes

- Crucial for event detection using Wake-on-WLAN
- Experimental setup (Airstrip, IIT Kanpur)
- Used methodology not optimal

Antenna at 802.11 radio end	**Antenna at 802.15.4 radio end**	**Distance**
8 dBi omni directional	3 dBi internal	240 m
8 dBi omni directional	8 dBi omni directional	380 m
17 dBi 90°	3 dBi internal	540 m
17 dBi 90°	8 dBi omni directional	> 870 m

802.11 detection using motes

- Further range improvement possible:
  - Lowering CCA (Clear Channel Assessment) threshold value to -94 dBm from default -74 dBm
- Range observed from usage of sector antenna can give simpler design
- Observed range during motion needs to be experimentally found out.

In motion 802.11 data transfer

- Needed to validate achievable data bandwidth when transferring from data aggregator to train.

Speed (mph)	Effective transfer time (s)	Total data transferred (MB)	Effective data transfer speed (Mbps)
5	219	92.3	3.4
15	89	44.2	4
25	58	26.9	3.7
35	37	14.5	3.1
55	19	7.9	3.3
75	12	6.3	4.1

**Data Source: R. Gass, J. Scott and C. Diot. Measurements of In-Motion 802.11 Networking In WMCSA'06, Apr 2006.*

In motion 802.11 data transfer

- Effective bandwidth similar for all speed.
- Current methods of performing handshakes, authentication etc. reduce the maximum data transfer possible.

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802.15.4 range with external antennae

- Range sufficient for line of sight operation

Antenna mounted at end-1	Antenna mounted at end-2	Range (in m)
3 dBi internal	3 dBi internal	75
8 dBi omni directional	3 dBi internal	75
17 dBi 90° sector	3 dBi internal	210
24 dBi 8 ° grid	3 dBi internal	500
8 dBi omni directional	8 dBi omni directional	90
17 dBi 90° sector	8 dBi omni directional	500
24 dBi 8 ° grid	8 dBi omni directional	800

**Data Source: B. Raman, K. Chebrolu, N. Madabhushi, D. Y. Gokhale, P. K. Valiveti and D. Jain. Implications of Link Range and (In)Stability on Sensor Network Architecture To appear in WiNTECH 2006, A MOBICOM'06 Workshop, Sep 2006.*

Effective rates

- Effective data transfer rates observed are much less than claimed maximum rate of 250Kbps
- Fastest sending rate
  - 54.56 Kbps (42.16 Kbps effective)
- Fastest reception rate
  - 40.46 Kbps effective
- Reasons
  - Implementation
  - Channel access etc.

FTSP

- Both modified and original implementation evaluated for beacon rates of 1,2,3,5,10,30 and 50 s.
- Experimental setup
  - Linear topology
  - Programmable beacon rate
  - 6 hop with node addressed 0-6
  - TOSBase node to snoop and send beacons

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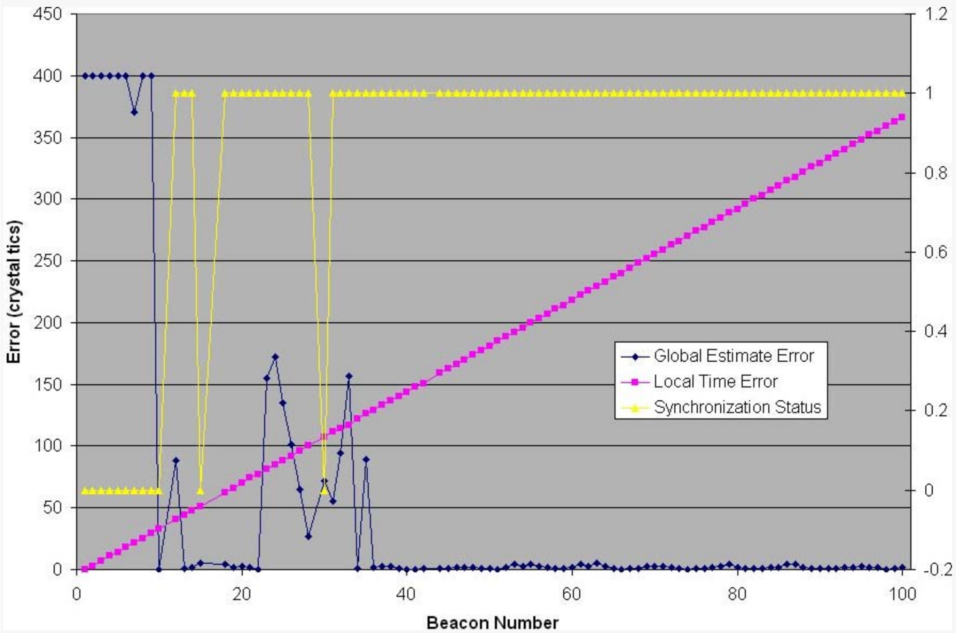
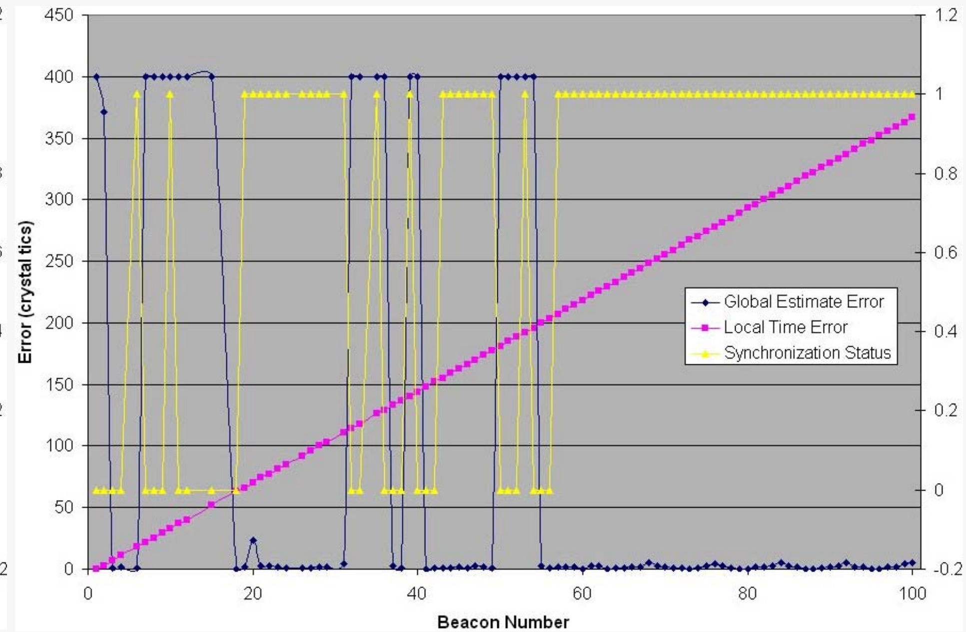
Node 1

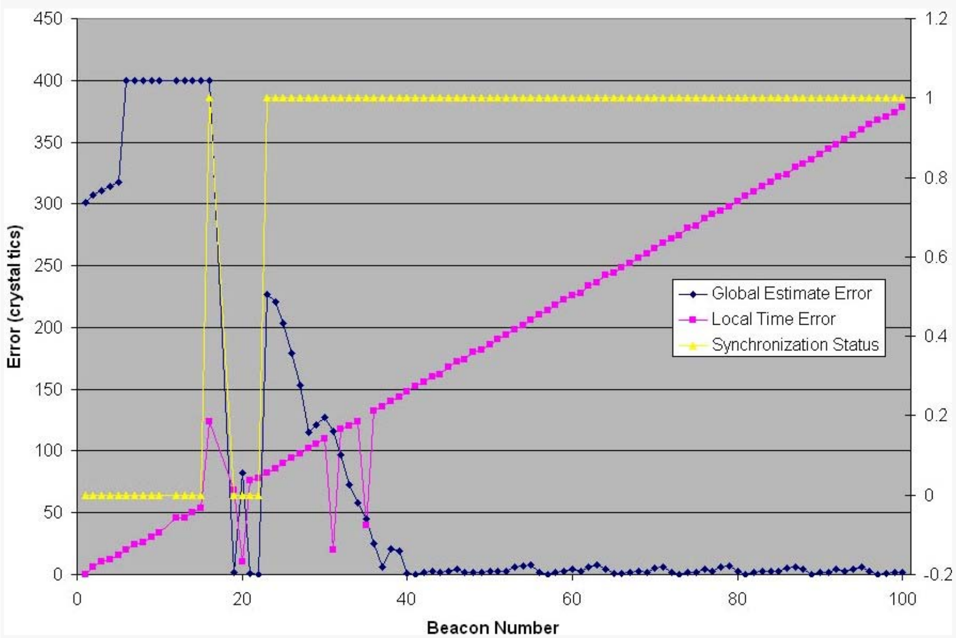


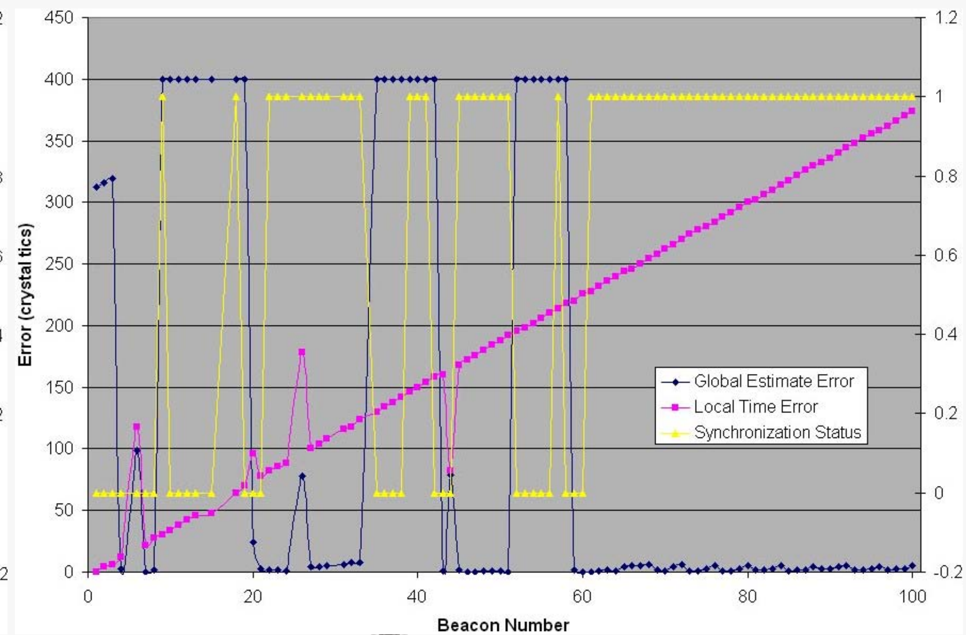


Modified

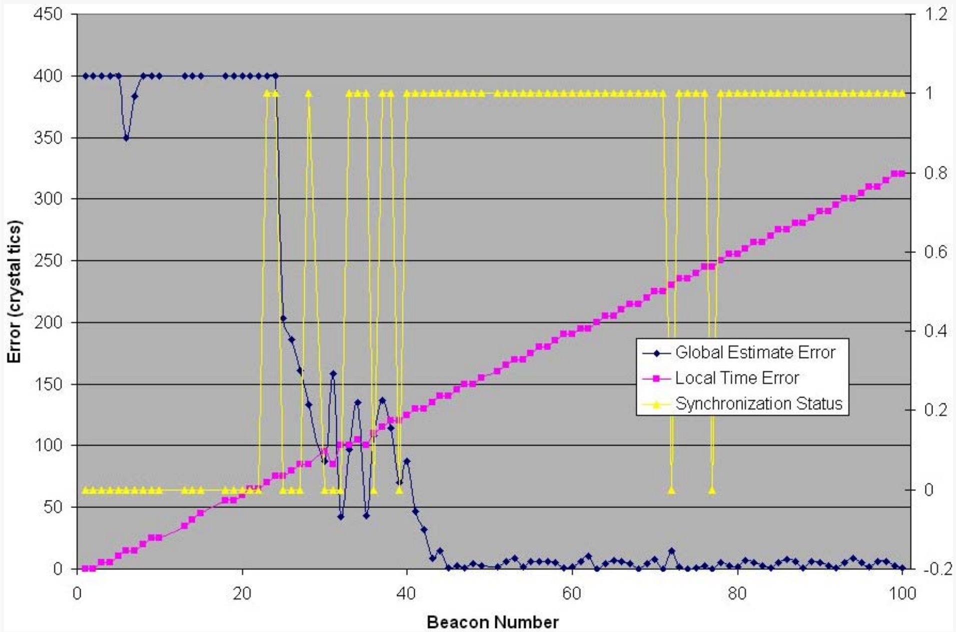
Node 2

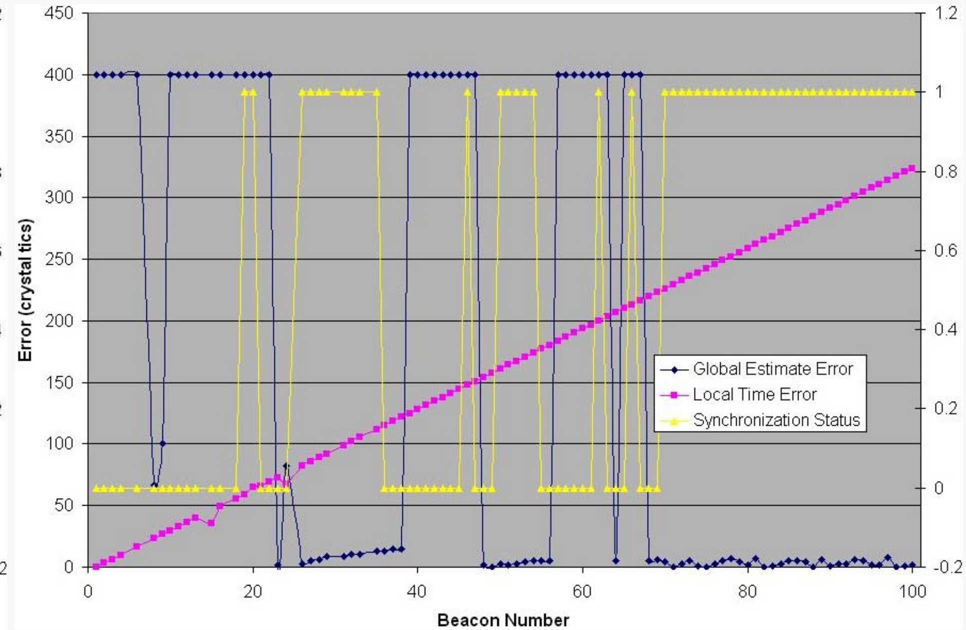
Original





Node 3

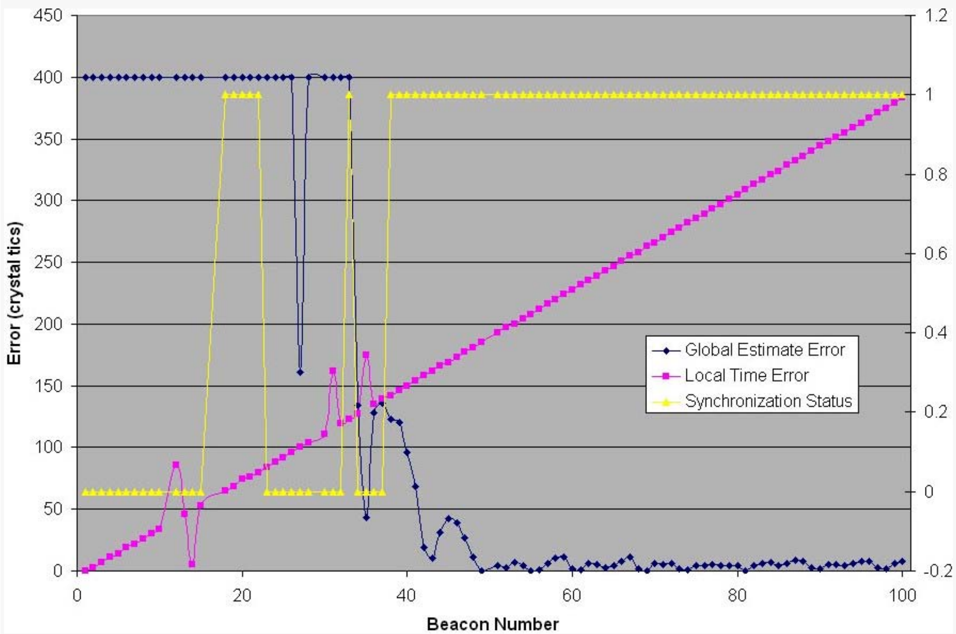


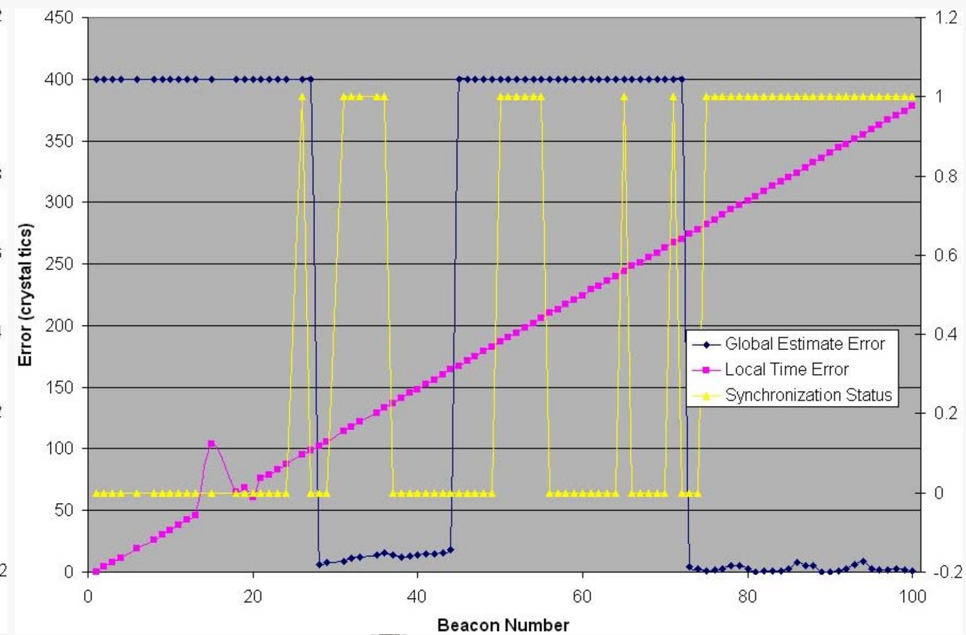


Modified

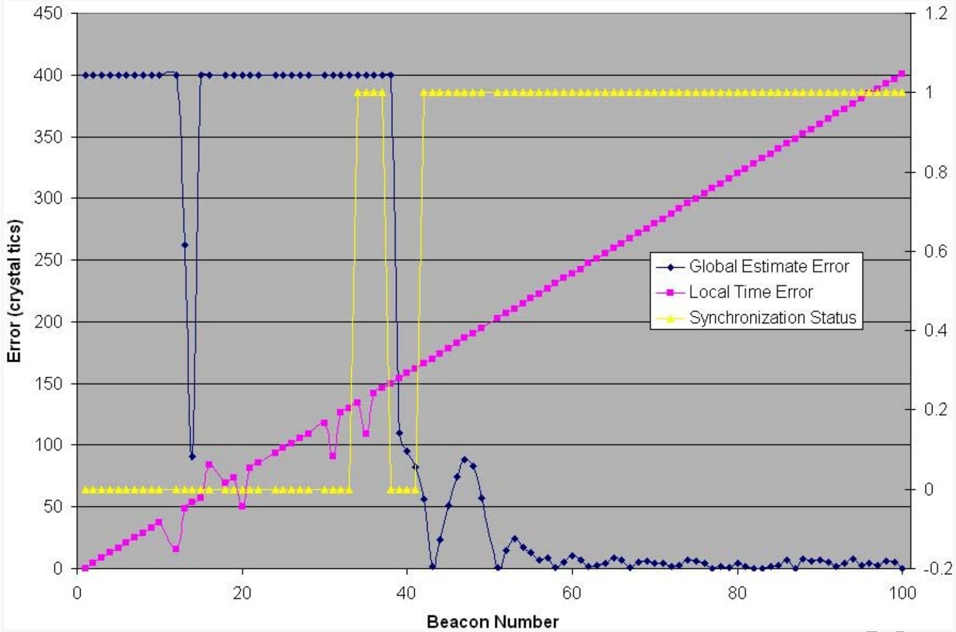
Node 4

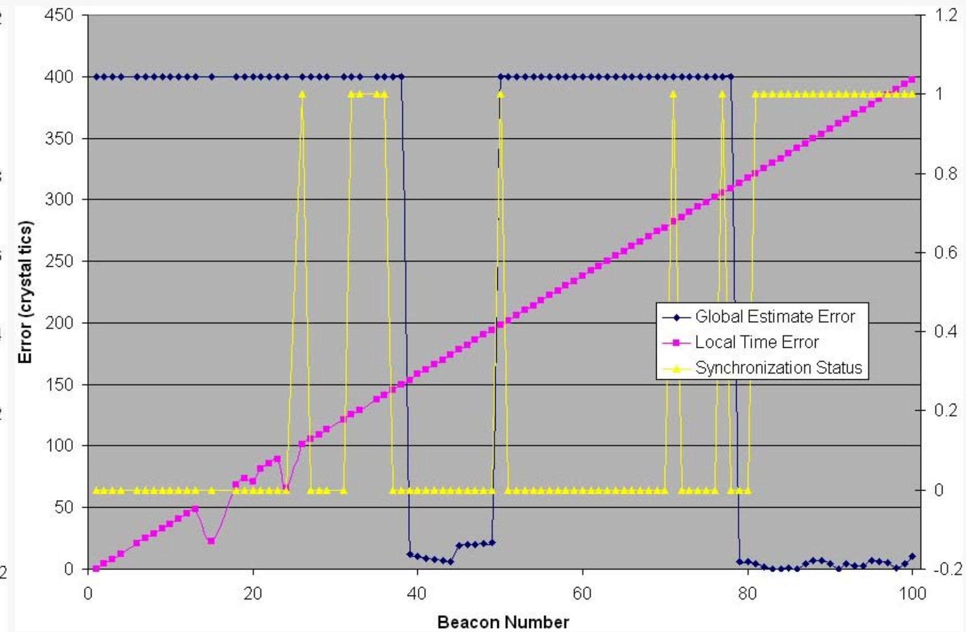
Original





Node 5

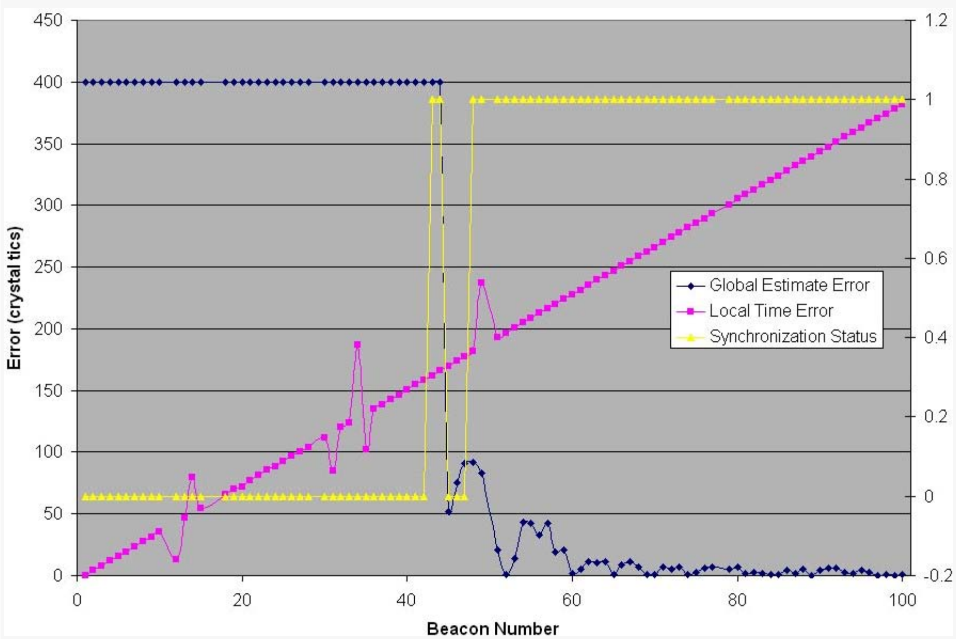


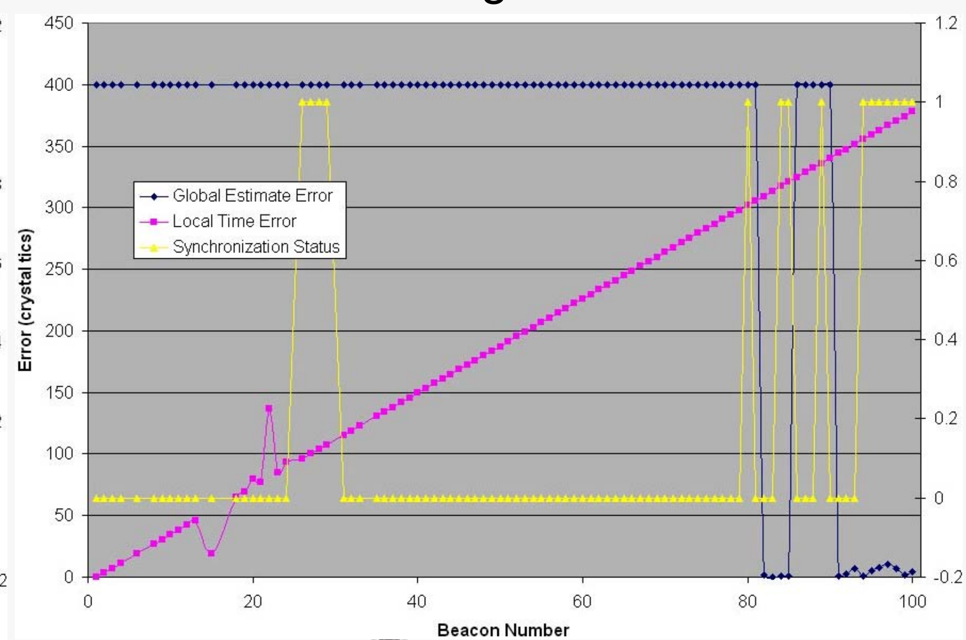


Modified

Node 6

Original





FTSP

- Our method gives more stable and consistent network wide synchronization.
- Synchronization achieved earlier in modified case.

Beacon Rate (s)	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6
2 (original)	5	91	-	-	-	-
2 (modified)	10	31	58	59	-	-
10 (original)	49	> 95	-	-	-	-
10 (modified)	14	20	34	68	72	-
50 (original)	19	27	26	31	81	94
50 (modified)	18	34	41	42	49	51

Least beacon id for stable synchronization (units is number of crystal tics, 1 crystal tic = 30.5 μs)

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FTSP

- Network wide stable synchronization achieved at earlier beacon id for larger beacon periods.
- Reasons
  - Timers not skew compensated (scattered firing)
  - Receive rates lesser than sending rates (packet drop)

Beacon rate	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6
2 s	73	78	73	72	78	73
10 s	82	83	86	82	82	83
50 s	92	93	93	92	93	92

Number of packets received at data logger for different nodes at different beacon periods

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Conclusion

- Definite benefits over wired systems in terms of cost, deployment and scale.
- Novel use of Wake-on-WLAN and train as transporter
- Model can be generalized and used over for data collection from scattered sensor network deployments.
- Future work: data compression, optimal time stamping, use of more sensitive MEMS accelerometers.

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Thank you!

Questions?

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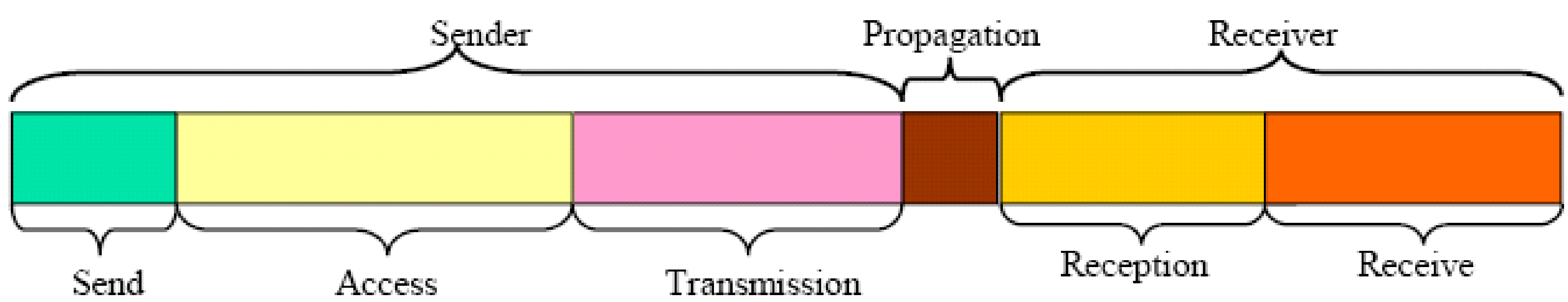
Analysis of radio transmission

- **Send Time**: Time used to assemble the message and send it to the MAC layer on transmitter side.(0-100 ms)
- **Access Time**: Time required to gain access over the channel. (Cannot be predicted accurately).(10-500 ms)
- **Transmission Time**: Time taken to transmit the message (10-20ms)
- **Propagation Time**: Time taken to transmit the message from sender to receiver once it leaves sender. (< 1ms)
- **Reception Time**: The time taken by the receiver to receive message.(10-20ms)
- **Receive Time**: Time taken to process the received message and notify the appropriate application. (0-100ms)



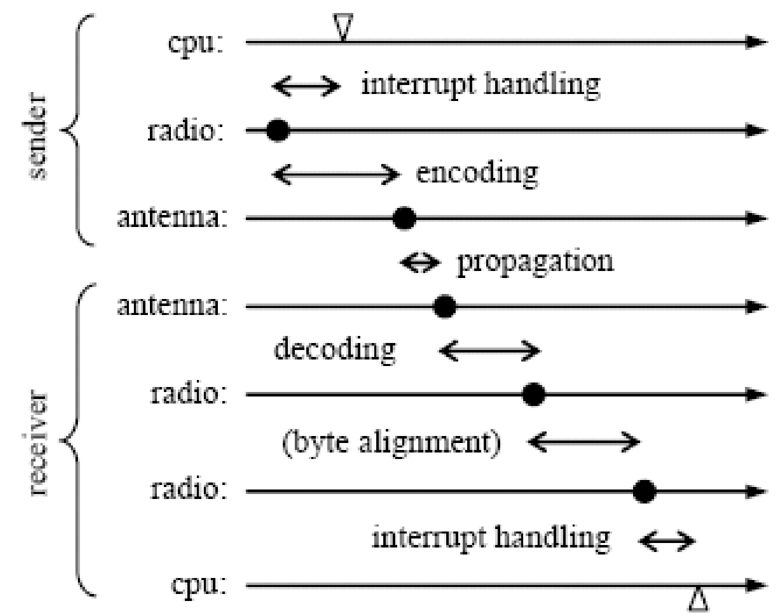
Decomposition of packet delay over a wireless link $

$ Figure borrowed from "Time-sync Protocol for Sensor Networks", Ganeriwal et al. *Sensys'04*

Analysis of radio transmission: Additional Delays

Additional Slides

- **Interrupt handling time**: Delay between radio raising an interrupt and microcontroller responding to the interrupt. (5-30 μs)
- **Encoding Time:** Time taken by the radio to take the message and convert to Electromagnetic waves (100-200 μs)
- **Decoding Time**: Time taken by the radio chip to decode the message from the EM waves received on the antenna. (100-200 μs)



. The timing of the transmission of an idealized point in the software (cpu), hardware (radio chip) and physical (antenna) layers of the sender and the receiver. $

$ Figure borrowed from "The Flooding Time Synchronization Protocol", Maróti et al. *Sensys'05*

So what plagues synchronization in wireless?

- Uncertainty and non determinism of wireless data transmission.
  - Send and receive time dependent on interrupt handlers response time
  - Access time depends on MAC and is indeterminist in most cases.

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Components of time-sync errors

- Clock offset
  - I follow London’s time you follow Delhi’s time.
  - Calculated using synchronization points
- Clock skew
  - My watch ticks faster than yours
  - Two components
    - Accuracy
    - Stability

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Clock Skew

Additional Slides

- Accuracy
  - Difference between claimed frequency and observed frequency.
  - Typical errors in the range of 0-100μs
    - i.e. On an average clock loose/gains 40μs per second
- Stability
  - Crystal frequency changes with time, temperature and usage
  - Two types
    - Short-term
    - Long-term
  - Clocks are assumed to have high short term frequency stability

Back

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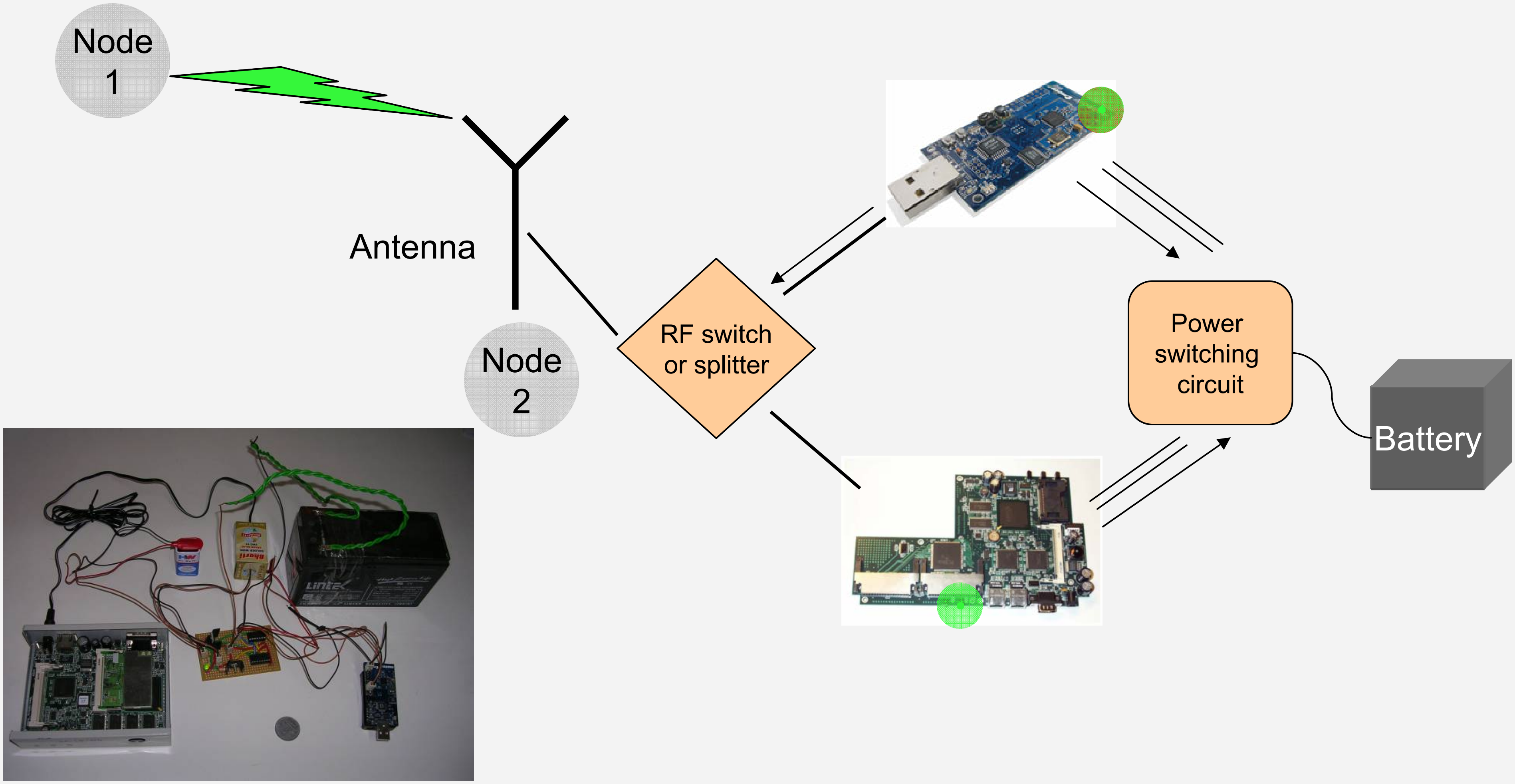
Wake-on-WLAN Architecture

Additional Slides



BriMon

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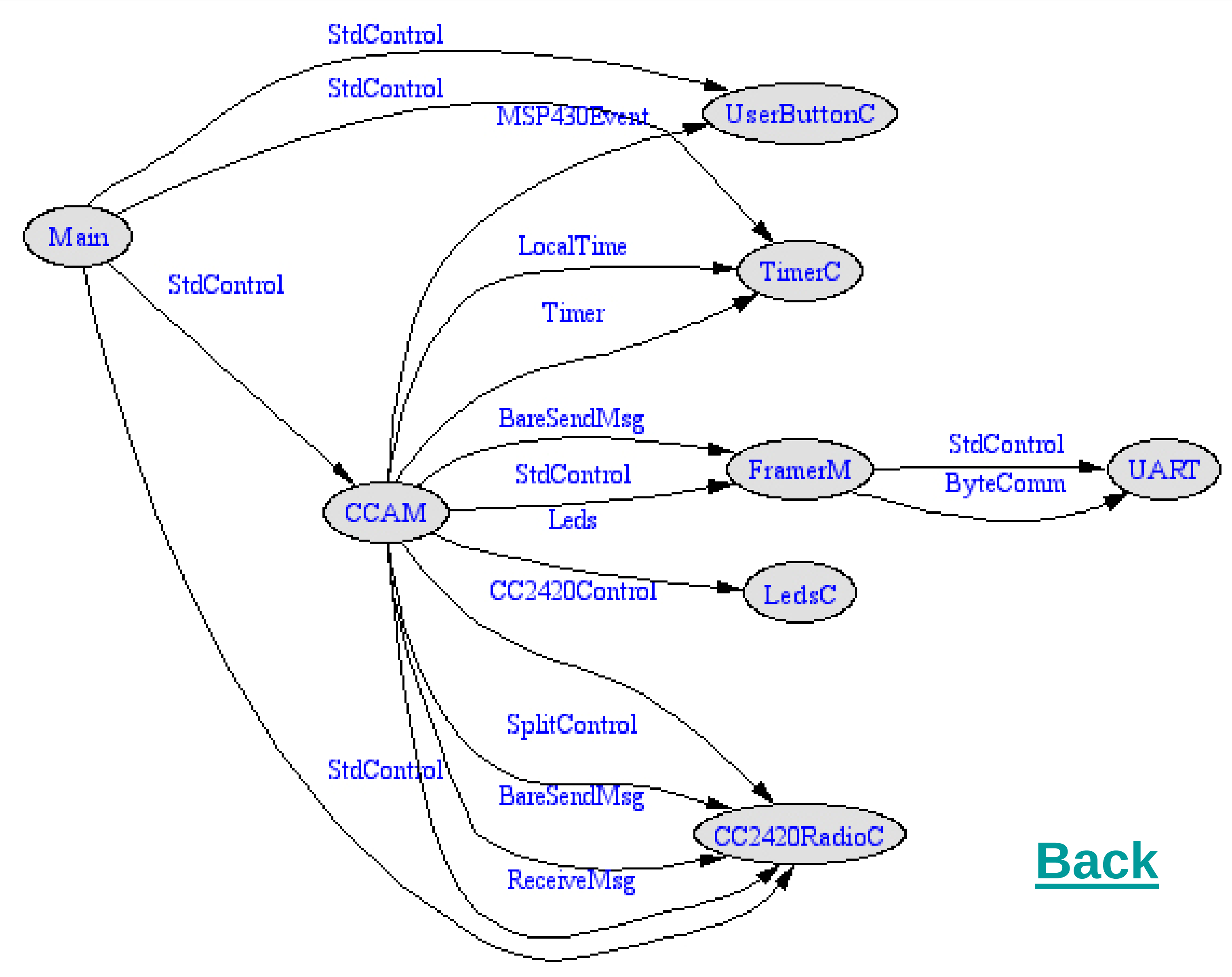
Wake-on-WLAN Implementation Details

Additional Slides

- Use of Chipcon's CC2420 CCA mode
- Configurable frequency and energy threshold parameters

CCA modes of 802.15.4

- Clear if energy below threshold
- Clear if valid 802.15.4 packet
- Clear if valid 802.15.4 packet and energy below threshold



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BriMon

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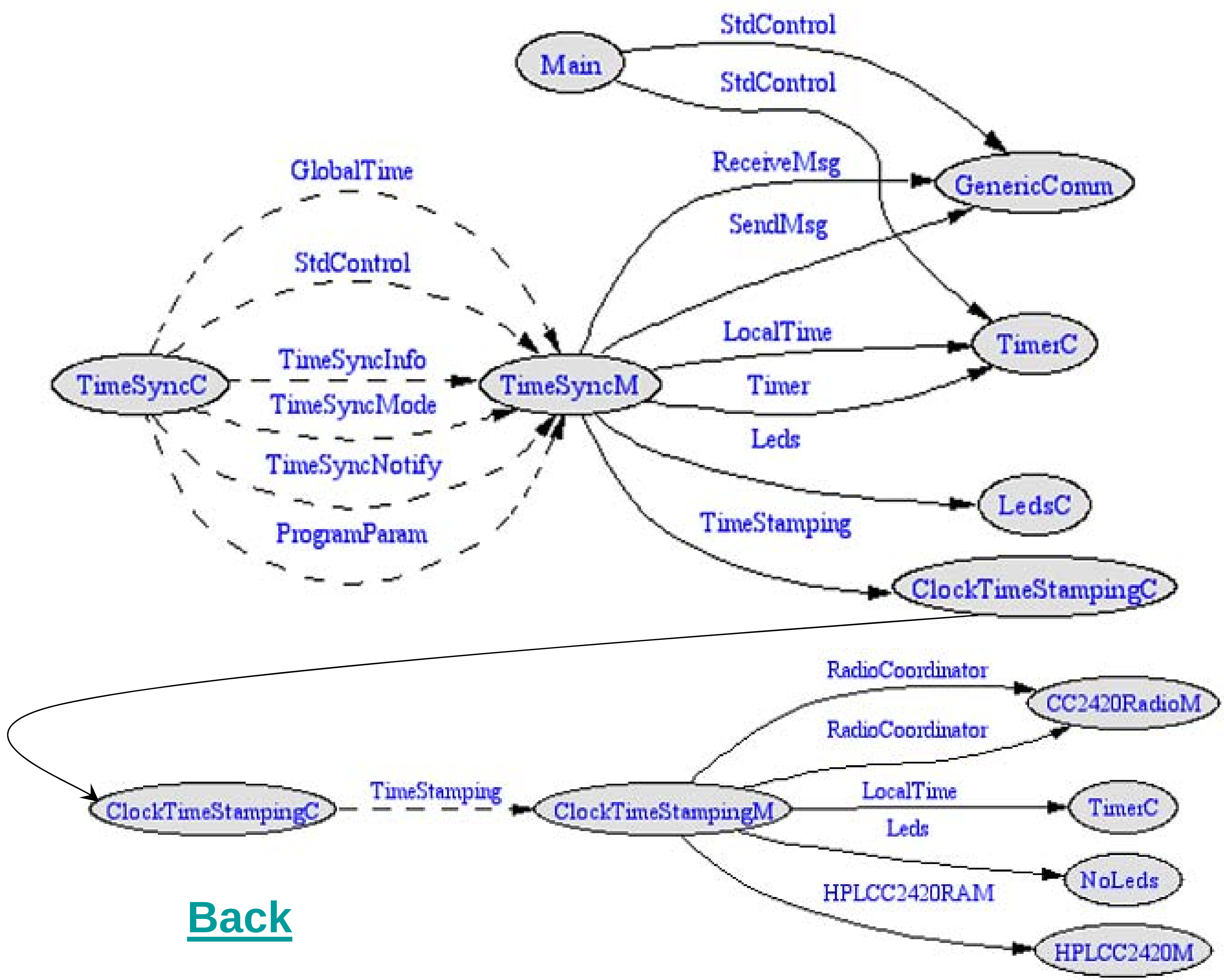

Main
StdControl
StdControl
GlobalTime
StdControl
ReceiveMsg
SendMsg
GenericComm
TimerC
LocalTime
Timer
TimeSyncInfo
TimeSyncC
TimeSyncM
TimeSyncMode
TimeSyncNotify
Leds
LedsC
ProgramParam
TimeStamping
ClockTimeStampingC
RadioCoordinator
CC2420RadioM
RadioCoordinator
TimeStamping
LocalTime
TimerC
ClockTimeStampingC
ClockTimeStampingM
Leds
NoLeds
HPLCC2420RAM
HPLCC2420M

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