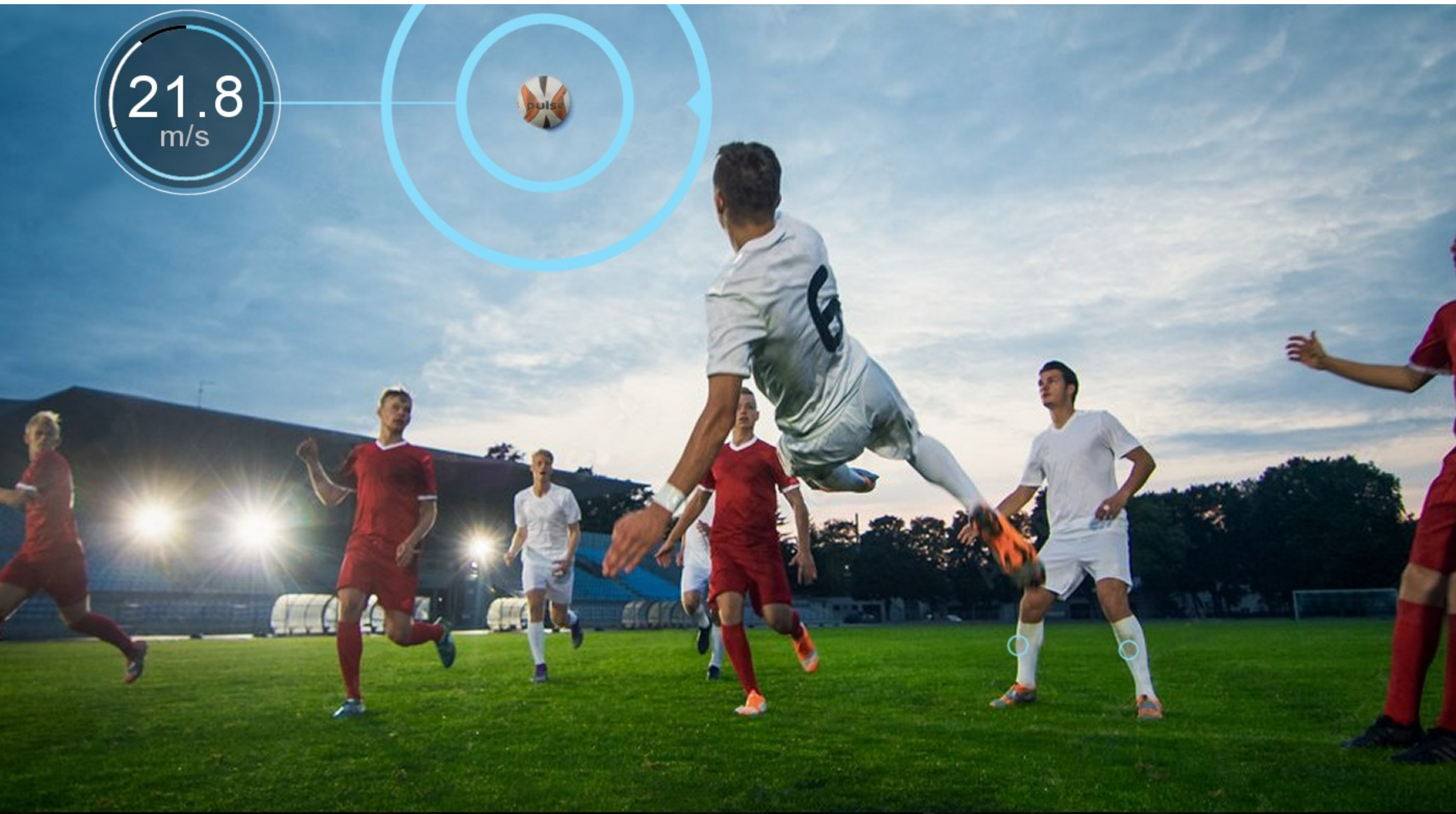

21.8
m/s


Speed max 10.8 m/s
Distance covered 550 m
CURRENT SPEED
10.2
m/s
Highest jump 75 cm
Time on court 14:24 mi

SUMMARY

Key system features

- Highest update rate in the industry, 3000 locates/sec (120 players with 25Hz position updates/sec)
- Easy setup with no requirement for master devices for synchronization
- Connect to any anchor and receive a full copy of the dataset of the network
- Instant optical performance feedback using full color LED panels on anchors
- Range: up to 300m (LOS) and anchors placed 4+ meter above ground
  up to 200m with tripod extended to 1.9m
  up to 50m with tripod at 0.7m (typical half-field training setup)

- Motion capture at 200Hz or 87.5 Hz (accelerometer, gyro, magnetometer)
- Tags on shin guards. Enables inverse kinematic full human-body-force modeling (injury prevention)
- Impact detection with 1ms accuracy
- Task executing for all devices within 60ns. For example simultaneous blink RGB panel on 4 devices
- Motion data compression (near lossless and fixed length encoding), allows for 15+% more tags
- Distributed UWB network administration (no single point of failure)
- Distributed UWB synchronization (no master anchor which is a single point of network failure)
- Infinite scaling. Deploy 1 UWB zone or multiple.

System capacity per UWB-channel per UWB zone (typical 200 x 200 meter).
2 Preamble length modes 128(*) and 256

- Industrial-mode-128: 3000 locates/sec, 26 anchors, 120 players @ 25Hz with 87.5Hz motion capture
- Sport-mode-256: 2150 locates/sec, 20 anchors, 82 players @ 25Hz with 87.5Hz motion capture
  Balls are tracked with 150Hz as position update rate, 200Hz motion capture, and 1ms impact detection

Deployment: The LPS system runs automatically 'out of the box' by placing 'anchors' upright on the sport field. When anchors are stored horizontally the anchors transition into sleep mode after 5 min. Ready for transportation. Tags check periodically if there is a valid network, else remain in sleep mode.

Tech specs:

UWB channel	: 3,4 and 6
UWB Bandwidth setting by default	: 6.8Mbps
UWB measurement Cycle duration	: 80ms
UWB Tag-time slots per cycle @ PLEN 128 (*)	: 124
UWB Tag-time slots per cycle @ PLEN 256	: 84
UWB Update rate (3D locates/sec)	: 2800

(*) Preamble length 'PLEN' = 128 symbols (Range approx. 90% of PLEN 256), 6.8Mbps

Example FIELD DEPLOYMENT: Performance and system capacity

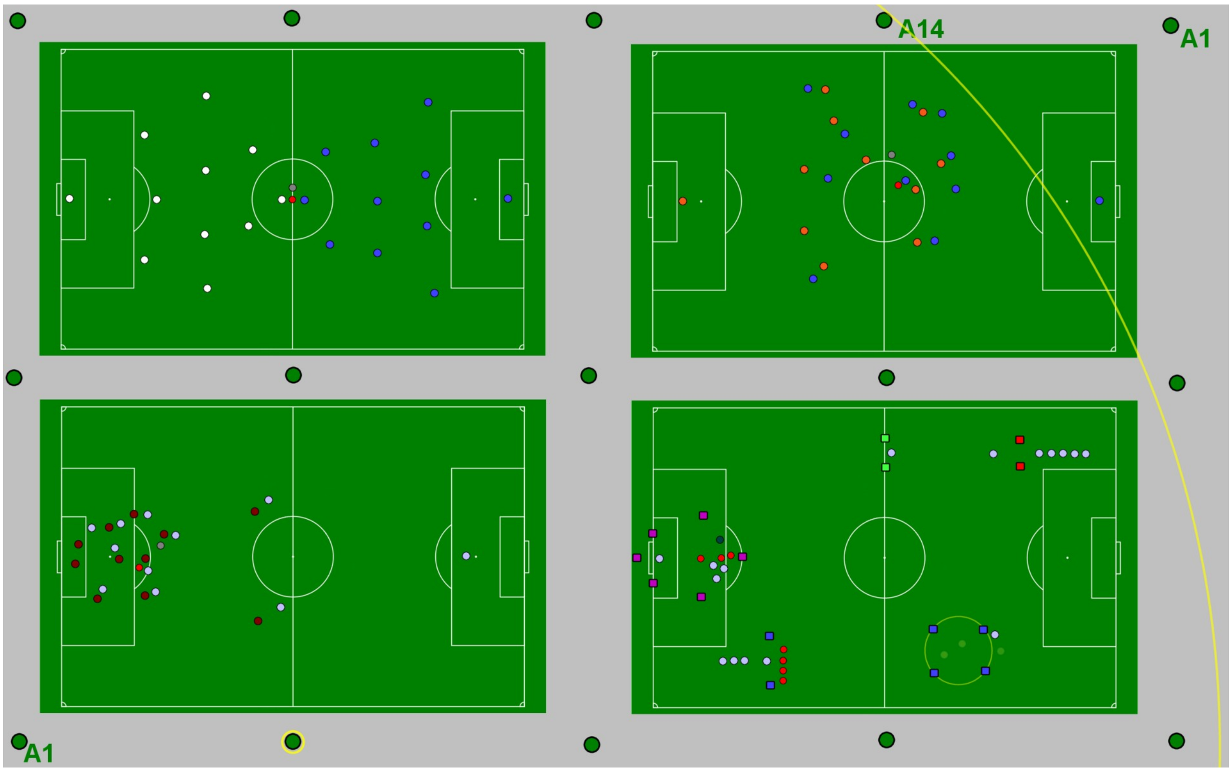


Figure 1: Sports-field area: 250m x 180m. 1 UWB zone. UWB mode: plen 128

Real-time simultaneous tracking of

6 teams: 66 players @ 25Hz (87.5Hz Motion capture)
3 referree
3 match-balls @ 150 Hz (200Hz Motion capture, 1kHz impact detection)

1 team-training on the lower right field (penalty shoot, sprint, passing/target practice)
15 players @ 25Hz (87.5Hz Motion capture), 2 mobile systems (6 anchors/system)
9 balls @ 50 Hz (200Hz Motion capture, 1kHz impact detection)

Total: 84 tags,12 balls, 26 anchors
11 field anchors 3+ m above ground: approx 250m range (figure 1:green dots yellow range circle)
3 field anchors with PoE Ethernet for data offload (A6, A8, A10)
12 mobile anchors 0.7m above ground: approx 50m range situated on the lower right training-field

Calculation of the required system capacity: 84 players x 25 + 3 x 150 + 9 x 50 = 3000 locates/sec.

Capacity doubling
2 UWB-channels can operate concurrently on an area covering 4 football fields

Scaling the system with 'infiniscale' technology
A novel way of synchronization and network scaling method ('infiniscale') is used in the system Additional fields start to re-use UWB-timeslots. For example anchor A1 on timeslot 1.
Multiple mobile anchors sets from multiple owners can be active without interference on the same field. So called 'master' anchors to provide synchronization service to the network are not used in this system since that would entail a single point of failure. A novel distributed wireless synchronization method has been developed to resolve this issue.

DATA FORMAT

Metrics of data-stream and storage format

Captured sessions file format consists of 3 sections of data.

1) Time and Device-ID + RAW-motion data in the columns on the left.
2) Calculated values like, position, distance traveled, speed and device details in the columns at the center.
3) Events Journal in the most right columns. Events like passes, ball possession, sprint finish, goals,

RAW-sensor data part

CycleID : Every cycle last 80ms. Time synchronization throughout a UWB network is better than 100ns.
Period : Every cycle consist of 5ms intervals. Using UWB-seat information events like an impact is timed to +/- 1 us
DID : Device-ID. A short number of a device in the network. In the device property list you can find the MAC-address and other relevant info like to which heart rate-belt a tag will connect automatically. Device Name. Battery status. The HWID (Hardware-ID) identifies the type/shape of the board (like mobile RGB anchor, etc) as a HEX value In decimal: HWID = 63 for a Ball tag, HWID = 71 for a mobile field anchor.
Ax Ay Az : X Y Z acceleration data. 1G is represented as 4096. Dynamic range +/-32G (+/-131072) continuously
Gx Gy Gz : X Y Z gyro data in mdps, milli degree per second. Dynamic range +/-4000 dps (+/-11 revolutions / second)
Mx My Mz : X Y Z magnetometer data in mGauss: if not switched on 32000 is default (32 Gauss)
W I J K : Quaternion

DID_A2A : Device-ID of anchor which performed the time of flight measurement to the corresponding tag DID
TOF_1 : Time of flight measurement converted to a distance. Expressed in dwt (1 dwt = 4.617mm)
TOF_2 : ,, ,, The suffix 1 to 16 indicates in 5ms/steps, when the measurement occurred during the 80ms cycle.
….
TOF_14 : ,, ,, . For events with 1ms resolution the exact timing is written in the 'Params' column.
ARSSI : UWB signal strength as received on the anchor in dBm. More conversion details in this document.
TRSSI : UWB signal strength as received on the tag. ,, ,,
QF : Quality factor of the UWB-signal. An evaluation of distance, standard deviation and signal strength

Calculated values

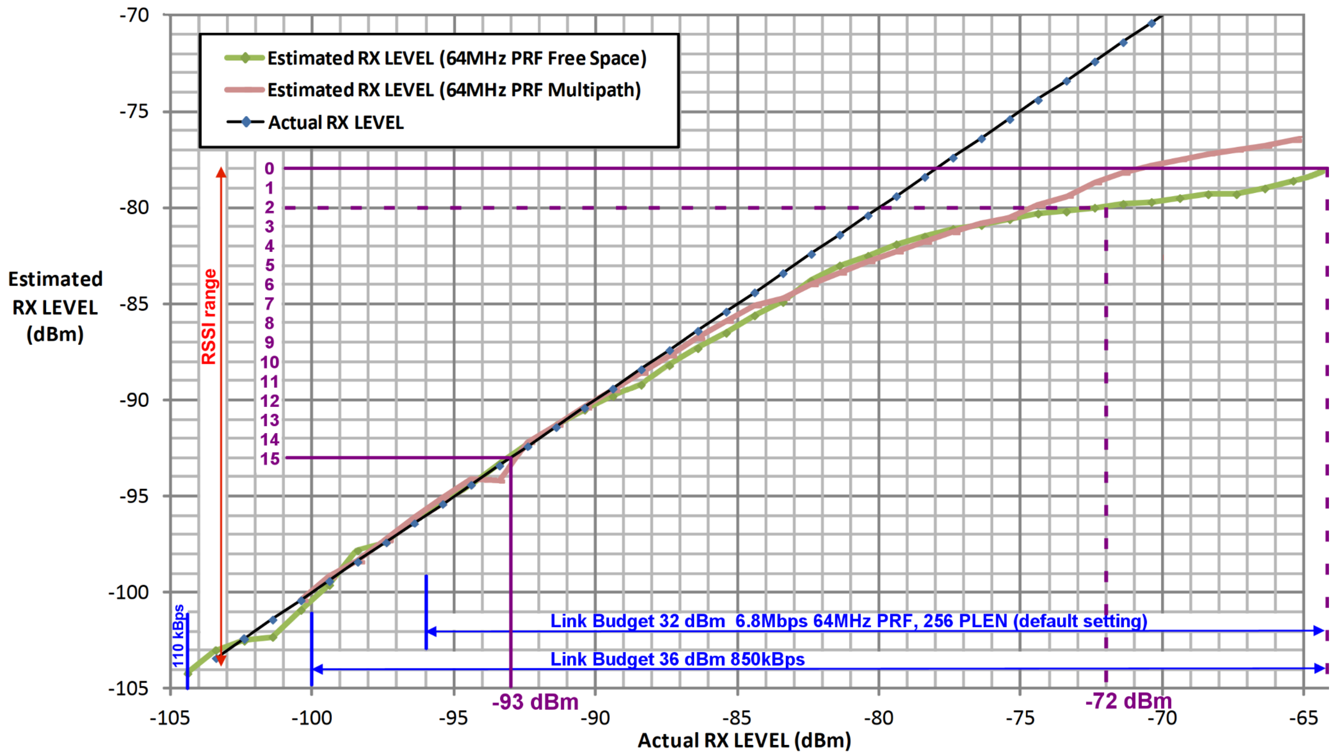
Xu Yu Zu : Raw UWB 3D position data at 50Hz default (max 200Hz) in mm
X Y Z : Smoothed 3D position data at 200Hz in mm
Speed : in m/s
Distance : in mm
Spin : in revolutions per sec. / 100

Journal part of the CSV file

Class : type of event, like kick or battery status report
Params : values/parameters of events and elements. For example properties of devices in the field are reported at the start of the recording of a session
MISC : miscellaneous

For every cycle the data per tag is collected.
Every cycle can also contain data with distances measured in between anchor.

UWB SIGNAL STRENGTH   RSSI and Range



UWB Signal strength is encoded in 1 byte. 2x4 bits for both directions [0..15] in TLV-data format.
See graph for conversion to Actual RX level dBm for RSSI values. As captured by the UWB-transceiver.

TLV report value 4bit [0.15]	Actual RSSI -dBm	TLV report value 4bit [0.15]	Actual RSSI -dBm
0	-64	8	-85
1	-68	9	-86
2	-72	10	-87
3	-76	11	-89
4	-79	12	-90
5	-81	13	-91
6	-83	14	-92
7	-84	15	-93

Total UWB radio signal link-budget in **’Free Space’ ~40dBm @64MHz PRF @110kBps**
Effective link budget at 6.8Mbps is about 32 dBm.
In general the signal strength drops 1dBm every 10 meter
MAX-range between 2 anchors with standard antenna's 32 x 10 = 320 meter with anchors placed 4+ meter above the ground. The max distance is shorter when anchors are placed closer to the ground.
Special long range antenna’s can increase the range to over 1km.

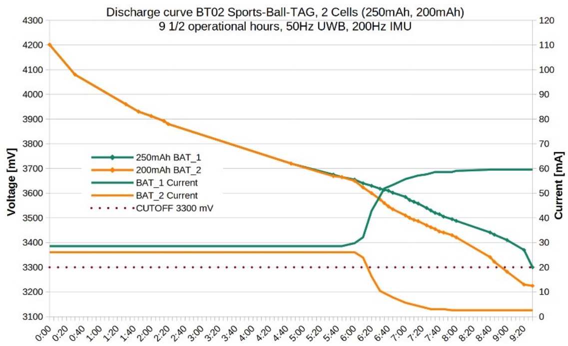
Attenuation, link-budget and range
A brick or concrete wall attenuates the UWB signal between 3 to 10dBm reducing the link-budget.
The attenuation depends on the 'attack-angle' (straight through the wall or at an angle).
The link-budget is sufficient for the UWB signal to travel through 2 or 3 brick walls inside a building.

MISCELLANEOUS

Battery voltage status
TLV value to battery voltage in mV
2790mV + value x 5.84mV/step = battery voltage

Pressure sensor in sports ball
TLV value to pressure inside ball in mBar
1atm + value x 4.8mBar/step = pressure inside the ball in mBar

Discharge curve, lifespan and TCO
The ball has 2 batteries in parallel. One cell might age faster.
Typically the better cell would then charge the weaker cell.
Special electronics make both cells to operate independent.
In the example a 200mAh cell parallel with a 250mAh cell.
The 250mAh cell last longer under load but does not charge
the depleted 200mAh cell (around the 6 hour mark).
Resulting in increased efficiency of the cells.



The ball tag operates for 9 ½ hours continously
at 50Hz UWB (50 locates/sec), 200 Hz IMU
For 2 x 250mAh cells up to 10 ½ hours

Lifespan
On Matchday: the ball is active for 99.5% of the time.
At training days, the ball is idle 66% of the time. The IMU motion capture sensors in the ball detect when the ball is 'idle'. The accelerometer will then detect a 1G gravity vector pointing to center earth which does not change direction over time. As long as this is the case the ball will operate in 'shallow sleep'.
In shallow sleep the ball is active for a few UWB cycles of 80ms then skips a few measurement cycles.
This reduces the energy consumption to around 20%, thus enhancing the operational hours per charge.
Lifespan/charge at training days is up to : 38 training hours.

TCO: Total cost of ownership
Lifespan of the ball: up to 400 charge cycles and about 10% battery-capacity degradation over time.
Total operational time for the electronics and battery is up to 14400 hours. (+/- 2 cent/hr)
Typically the 'first' team use match-balls for about 1 year.
Then pass it to lower level teams for another 1 to 2 year use.
Typically 3 years of operation before replacement.
TCO: 100eu/year/ball, 2000hours/year. 200 training days/year, active for 10hours per training-day

SPRINT DATA recording
See data-file about sprint @ https://airtls-sport.eu/download/20240110_1130_12538.csv

Typically the 2 tags are worn in calf sleeves over the shinguard on the lower legs.
Alternative is to wear 1 tag in a vest near the C6 bone. The advantage of 2 tags at the lower leg is to enable to determine loads on the knee joints and hamstring muscle. To prevent premature injuries during training. 1 tag on one leg is also possible as per example.

Below a summary on how performance data is extracted from the recorded LPS data file of a (slow sprint). The performance metrics of a sprint ends up in the CSV file journal (column Class and Params)
For this recording at Cycle 4970:
FINISH:Passed_distance:4318_speed:1.48_time:1456_maxSpeed:1.57_maxSpeedPos:88

The sprint performance metrics are stored in the local performance database and shared on the cloud. The raw data file (CSV) can be deleted. The CSV is useful for replay in 3D and for trainers and coaches to add comments and share this with the athlete(s).

FINISH: BF07 res:Passed_distance:4318_speed:1.48_time:1456_maxSpeed:1.57_maxSpeedPos:88
The local time and GPS position of the mobile phone which acted as a recording device on the field is written at the start of the file. The rest of the file operates based on 80ms cycle which are split into 16 periods or 5ms/cycle.

The start gate of the sprint exercise is formed by 2 anchors at the field line Y=0.
Likewise the finish line is formed by 2 anchors. When an athlete passes the finish the RGB panels blink a pattern which shows the change in performance relative to earlier know performance.
The recording of all events and tracked tags is fully automated.

TAG: BF0700	Cycle ID	Period	X	Y
START	4952	7	889	-3
	4952	8	891	4
FINISH	4970	11	156	4249
	4970	12	151	4259

START LINE IS at Y = 0,
FINISH LINE IS at Y = 425 cm
Max speed of the lower leg going forward at cycle 4968 period 7 [4968:7] at 3.15 m/s
Human body travels at half the speed of the lower legs
Duration of the sprint Cycle 4952:7-8 to 4970:11-12 = 18 cycles of 80ms + 3,2 periods of 5ms
Foot hit the ground at Cycle 4952:4, position X 885, Y -24,
Next foot ground hit at Cycle 4961:8, position X 643, Y 2037
Stride 2075mm, Stride period = 700 ms

Sprint Performance metrics		Unit	Notes
Sprint duration from start to finish	1456	ms	
Sprint Distance	4318	mm	Slightly diagonal path
Speed of lower leg	**2.96**	m/s	
Speed max of lower leg	**3.15**	m/s	Cycle 4968 Period 7
Speed of human body	**1.48**	m/s	Half of the lower leg(s) speed
Start acceleration of human body	**4.22**	m/s^2	Body weight 85kg, 1,96m. 90 Joule Kin.-Energy
Stride	2075	mm	
Point of max speed of total distance	88	%	Max speed near the end

LPS versus Optical Timing Gates and GPS sprint tracking.

Optical timing gates can not compensate for *not* running a straight line. Only when an athlete runs a straight line will the numbers match real-world performance. In the above case this error is **1.6%.** Timing gates can not record who passed the gate, nor record the max speed during the sprint.

GPS tracking system have typically **10% up to 20% error in the max speed**
and **2 to 5% error in average speed** recording. Especially when sprinting distances below 20 meter.
GPS position errors range from 0.3 to 3 meter. GPS update rate: 10 position samples per sec.
With a sprint speed of 8m/s the 20meter trajectory is covered by 20/8 = 25 samples at <+/-1m accuracy
3th party research on catapult system: https://hightecinsport.com/sport/tech/gps/gps_sport_tracking.html

LPS sprint of 20meter at 8m/s is covered by 125 samples at +/- 2.5cm accuracy/sample
Error in average speed **<0.1%**
Error in max speed **<0.1%**

CONCLUSION:
When training to improve 10ms@100 meter, using evaluation tools with sub 0.1% accuracy matters.

PHY

```
def cmd_blink(pattern: int, brightness: int, cycle_id: int, did1, did2):
def cmd_blink_immediately(pattern: int, brightness: int, did1, did2, did3):
def cmd_shutdown(did1, did2, did3, did4):
def cmd_set_uwb_config(ch3: int, ch5: int, txpower: int, did1, did2):
def cmd_set_board_config(config: int, did1, did2, did3):
def cmd_factory_reset(did1, did2, did3, did4):
def cmd_set_network_config(primary_seat, frequency, allocator_type, device_type, did1):
    Sets Network device config
    Args:
    - primary_seat - absolute seat number
    - frequency:
        0 - Unknown      (should not be used),
        1 - Random Tag   (not implemented),
        2 - VerySlow Tag (not implemented),
        3 - Slow Tag     (not implemented),
        4 - 25Hz,
        5 - 50Hz,
        6 - 75Hz,   (not implemented)
        7 - 100Hz,  (not implemented)
        8 - 125Hz,  (not implemented)
        9 - 150Hz,
    - allocator_type:
        0 - static
        1 - dynamic strict
        2 - dynamic relaxed
    - device_type:
        0 - None    (should not be used),
        1 - Dummy   (should not be used),
        2 - Anchor,
        3 - Tag,
        4 - Sniffer,
def cmd_set_random_period(period: int, did1: str, did2: str):
def cmd_set_network_start_delay(delay: int, did1: str, did2: str, did3: str):
def cmd_set_name(name: str, did: str):
def cmd_set_group(group: str, did1: str, did2: str):
def cmd_set_serial(serial: int, did: str):
def cmd_set_calibration_imu(  acc_bias: Tuple[int, int, int],    did: str,):
            - acc_bias - acceleremoeter zero offset compensation
def cmd_set_calibration_mag(mag_bias: Tuple[int, int, int],  mag_scalar: Tuple[int, int, int],  did: str,):
def cmd_set_message(message: str, did: str):
def cmd_update_license(key: str, ticks: int, did: str):
def cmd_set_heart_rate_mac(mac: str, did: str):
def cmd_set_ble_config(    power: int,    did: str,):
            - power - BLE TX radio power preset value
```

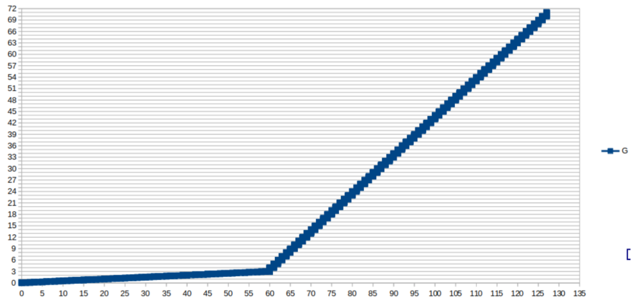
TODO:

SET IP, DHCP
SET Shutdown ESP
SET DISPLAY CANVAS (4 ACP commands)

Motion Byte- 8 bits characterizing device movement

•bit 0-6 - dynamic range - 7 bit value of average acceleration vector:
range 0-59 - step 0.05g
range 60-127 - step 1g

bit 7 - device is facing up - Y Axis is above 45 degrees.



ToF_TagImpactReport_t fields

0-2	3 bytes (array uint8)	`did`	Three bytes long Tag ID
3	1 byte (uint8)	`hitCycleOffset`	Impact hit detection in miliseconds relative to the start of the cycle
4	1 byte (uint8)	`motionByte`	Motion byte characterizing device movement

Defined as: …

0x80 - Command Set Serial

Byte	Storage	Field	Description
0-2	3 bytes (array uint8)	`did`	Three bytes long Node ID
3-6	4 bytes (uint32)	`serial`	Serial number
7-11	5 bytes (array uint8)	`padding`	Command padding, unused

0x81 - Command Set Group

Byte	Storage	Field	Description
0-2	3 bytes (array uint8)	`did 0`	Three bytes long Node ID
3-5	3 bytes (array uint8)	`group 0`	Device group name, UTF-8 encoded, NULL termination not required
6-8	3 bytes (array uint8)	`did 1`	Three bytes long Node ID
9-11	3 bytes (array uint8)	`group 1`	Device group name, UTF-8 encoded, NULL termination not required

0x82 - Command Set Name

Byte	Storage	Field	Description
0-2	3 bytes (array uint8)	`did`	Three bytes long Node ID
3-11	9 bytes (array uint8)	`name`	Device logical name, UTF-8 encoded, NULL termination not required

0x83 - Command Set IMU Calibration

0x84 - Command Set Message

0x85 - Command Update License

Byte	Storage	Field	Description
0-2	3 bytes (array uint8)	`did`	Three bytes long Node ID
3-10	8 bytes (array uint8)	`licenseKey`	License key used to authorize update request
11	1 byte	`tickUpdate`	Number of license ticks add or removed from the target device

0x86 - Command Set Magnetometer Calibration

0x87 - Command Set Heart Rate MAC

0x88 - Command Set UWB Config ← BLE

0x8B - Command Set UWB Config

0x8C - Command Shutdown (kill)

0x8D - Command Set Board Config IMU, sleep

0x8E - Command Set Network Configuration

Freq, Role, Admin type 2-very slow (1/256 cycles), 3-slow 1/20 cycles

0x8F - Command Set Random Period (2B period in seconds)

0x90 - Command Set Network Start Delay

0xC6 - Command Factory Reset

0xC8 - Command Blink Immediately

0xC9 - Command Blink