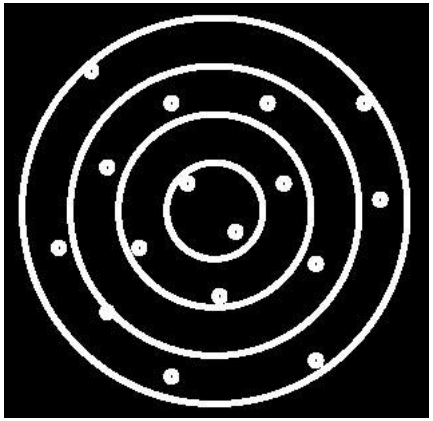
Indoor Positioning System

(with ±2cm accuracy)

For autonomous
vehicles, robots, drones,
forklifts and humans

Marvelmind
robotics

Problem to solve



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Problem

- GPS does not work indoors:
  1. No direct view of satellites
  2. Location accuracy is measured in meters rather than in centimeters (required indoor)
- Other indoor positioning systems - UWB, Bluetooth beacons, odometry, magnetometers, WiFi RSSI, laser triangulation, optical, etc. - have their own serious limitations – usually, either accuracy, price, or size
- Without precise and timely knowledge of location, autonomous navigation is impossible

Solution

- Off-the-shelf ready-to-use indoor positioning system based on stationary ultrasonic beacons united by radio interface in license-free ISM band
- The location of a mobile beacon installed on a robot (vehicle, drone, human) is calculated based on the propagation delay of ultrasonic signal to a set of stationary ultrasonic beacons using trilateration

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Indoor “GPS” (±2cm)

- Starter Set configuration:
  - 1 x mobile beacon – 119 EUR
  - 4 x stationary beacons – 4x119 EUR
  - 1 x modem/router – 119 EUR
  - All required SW included

Ready to use 3D (x, y, z) system for 599 EUR

The starter set covers up to 1,000m²
Get additional stationary beacons to expand to 200,000m² and beyond

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Selected customers

Customers in 50+ countries

On the market since 2014

Use case: Autonomous robots

1) Automatic delivery (10-100kg) in warehouses and assembly plants
2) Modified versions for customized applications: scanning, spraying, inspecting, photometry, different types of repetitive measurements

Advertising robots with high-tech charm - shows, shopping malls, conferences, museums

Micro-delivery (1-10kg) in an industrial environment: samples, gauges, cameras

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Use case: Autonomous drones

Autonomous indoor drones for inventory management and inspection

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Use case: Vehicles

Use case:

- Tracking vehicles, buggies, trolleys, forklifts, and other mobile assets in warehouses, in passenger and cargo areas of airports, in tunnels and mines

Problems solved:

- Accidents: collisions and speeding
- Broken equipment and goods
- Lost or underutilized mobile assets

Benefits:

- Precise knowledge of who is doing what and where ⇒productivity increase
- Real-time data about speed, acceleration, and position of the mobile assets ⇒ productivity increase
- Preventing accidents and decreasing insurance and other avoidable costs

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Use case: People

Tracking workers' location in factories, underground, in metro or tunnels, on construction sites, railways stations or under bridges

Use case:

- Underground/mining/metro
- Construction sites
- Factories
- Dangerous manufacturing
- Oil refineries and gas companies

– Increasing productivity
– Increasing safety

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Safety with working cranes and people

Mobile geofencing zone on crane boom

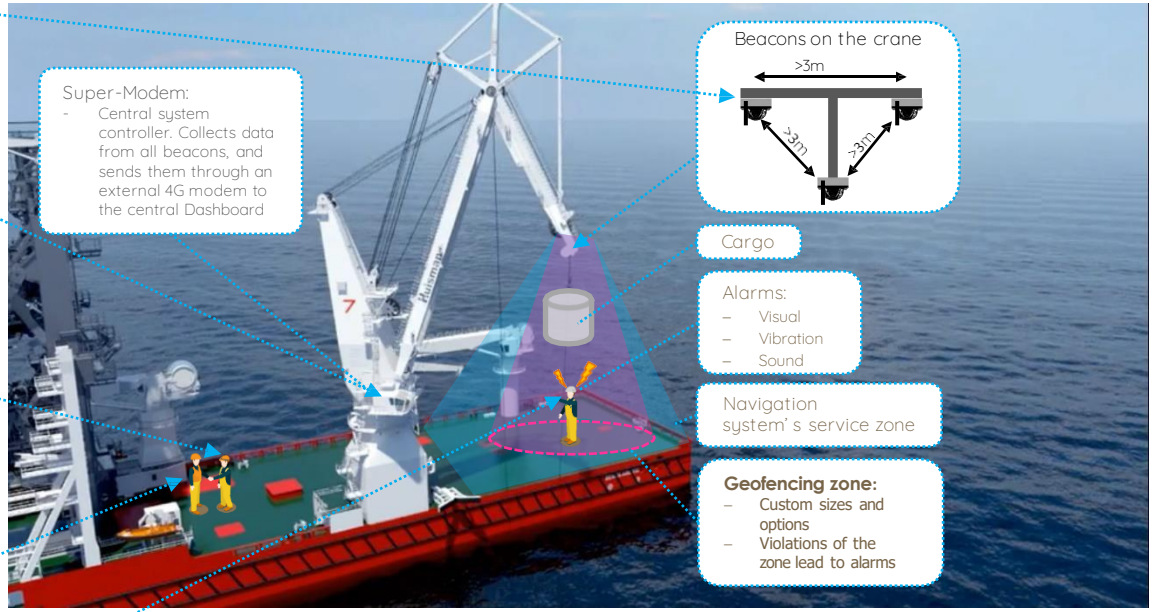
Ind. Super-Beacon

Super-Modem

Marvelmind Headlight

Marvelmind Jacket

Marvelmind Helmet



Configuration:
- N x Industrial Super-Beacon-Plastic (mounted on the boom)
- N x Marvelmind Headlight (1 per worker, placed on the helmet)
- 1x Super-Modem (placed in the center)

Principle of operation:
- In this configuration, the end of the crane boom is a card, the entrance to the Geofencing zone of which will warn the person and operator about a dangerous proximity

Result:
- High precision tracking Marvelmind Indoor GPS
- Alarm for workers and shift supervisor
- CSV file with a recording of all movements during the shift
- Automatic recording of all violations in a file for further analysis (optional)

Task:
- To prevent dangerous proximity and collisions of cargo with a person

Solution:
- Marvelmind Indoor GPS system installed directly on the crane with a mobile geofencing zone, which moves after the crane's boom

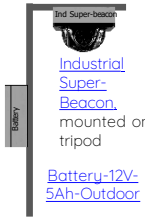
Marvelmind robotics

Safety at the construction site

Static and mobile geofencing zones at a construction site

Super-Beacon-Outdoor, mounted on a tripod

or



Industrial Super-Beacon, mounted on a tripod

Battery-12V-5Ah-Outdoor

Super-Modem

Marvelmind Headlight

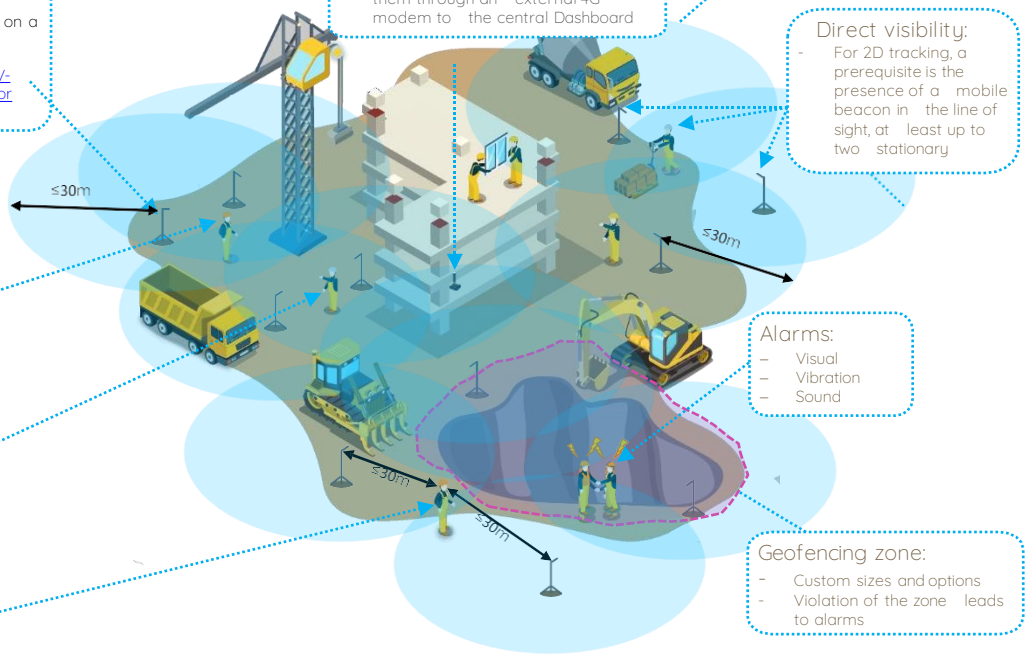
Marvelmind Jacket

Marvelmind Helmet

Super-Modem:
- Central system controller. Collects data from all beacons and sends them through an external 4G modem to the central Dashboard

Navigation system's service zone

Direct visibility:
- For 2D tracking, a prerequisite is the presence of a mobile beacon in the line of sight, at least up to two stationary



Alarms:
- Visual
- Vibration
- Sound

Geofencing zone:
- Custom sizes and options
- Violation of the zone leads to alarms

Configuration:
- N x Industrial Super-Beacon-Plastic (mounted on a tripods)
- N x Marvelmind Headlight (1 per worker, placed on the helmet)
- 1x Super-Modem (placed in the center)

Principle of operation:
- The Marvelmind Indoor GPS system in this configuration provides tracking of people with customizable geofencing zones and warns a person of approaching danger

Result:
- High precision tracking Marvelmind Indoor GPS
- Alarm for workers and shift supervisor
- CSV file with a recording of all movements during the shift
- Automatic recording of all violations in a file for further analysis (optional)

Task:
- To warn employees on approach to the dangerous zones; to obtain data on the movement of people

Solution:
- Marvelmind Indoor GPS system installed on-site with customizable geofencing zones

Marvelmind robotics

Autonomous DJI drones indoors

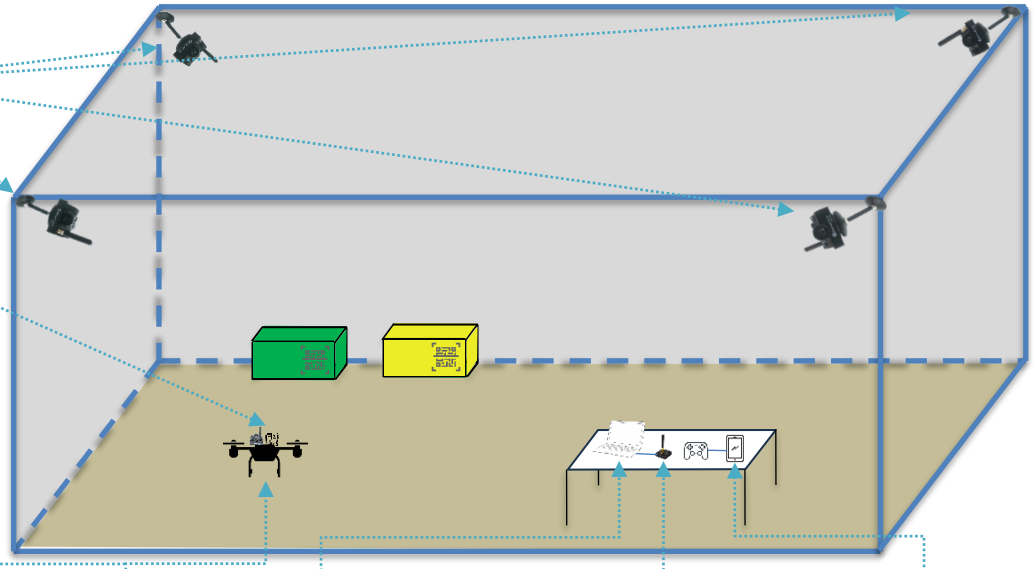
An example for 20x20 meter submap + 1 drone

Super-Beacon
(stationary beacon)

Super-Beacon
(Mobile beacon)
Lightened battery + no housing

Modem HW 5.1

DJI drone



DJI drone:
- Marvelmind system supports DJI drones starting from DJI Mini 3. Integration works via DJI SDK

Dashboard:
- Used for the setup of a system. Visual drone tracking. Streams to your ERP and WMS

Modem HW 5.1:
- Central controller of the system. Collects data from all beacons and communicates via USB/virtual UART with Dashboard

Marvelmind app + DJI RC:
- Special Marvelmind Android app, which allows one to control a system remotely. Connects to a DJI RC

Task:
- To provide an autonomous indoor flight for DJI drones
- Automatic take pictures, scan QR codes, send location data

Solution:
- Marvelmind Indoor GPS system with a Marvelmind app for autonomous flight

Configuration:
- 3-4 x Super-Beacon – stationary beacons
- 1 x Super-Beacon – a mobile beacon
- 1 x Modem HW 5.1 – a central controller
- 1 x DJI drone – a trackable object
- 1 x DJI RC + Android phone with Marvelmind DJI app – a controller of an autonomous fly pattern of a drone
- 1 x Windows/Linux laptop – used to install Dashboard and set up a system

Principle of operation:
- The Marvelmind Indoor GPS system in this configuration provides tracking and autonomous flight of a DJI drone using DJI SDK

Result:
- DJI drones autonomously flying according to waypoints in the Dashboard, taking pictures or scanning and recognizing QR/bar codes, and sending them along with their precise coordinates to WMS or ERP
- Autonomous return to the base

Marvelmind robotics

Huge AGV, transport and people

Mobile geofencing zone on AGV

Ind Super-Beacon

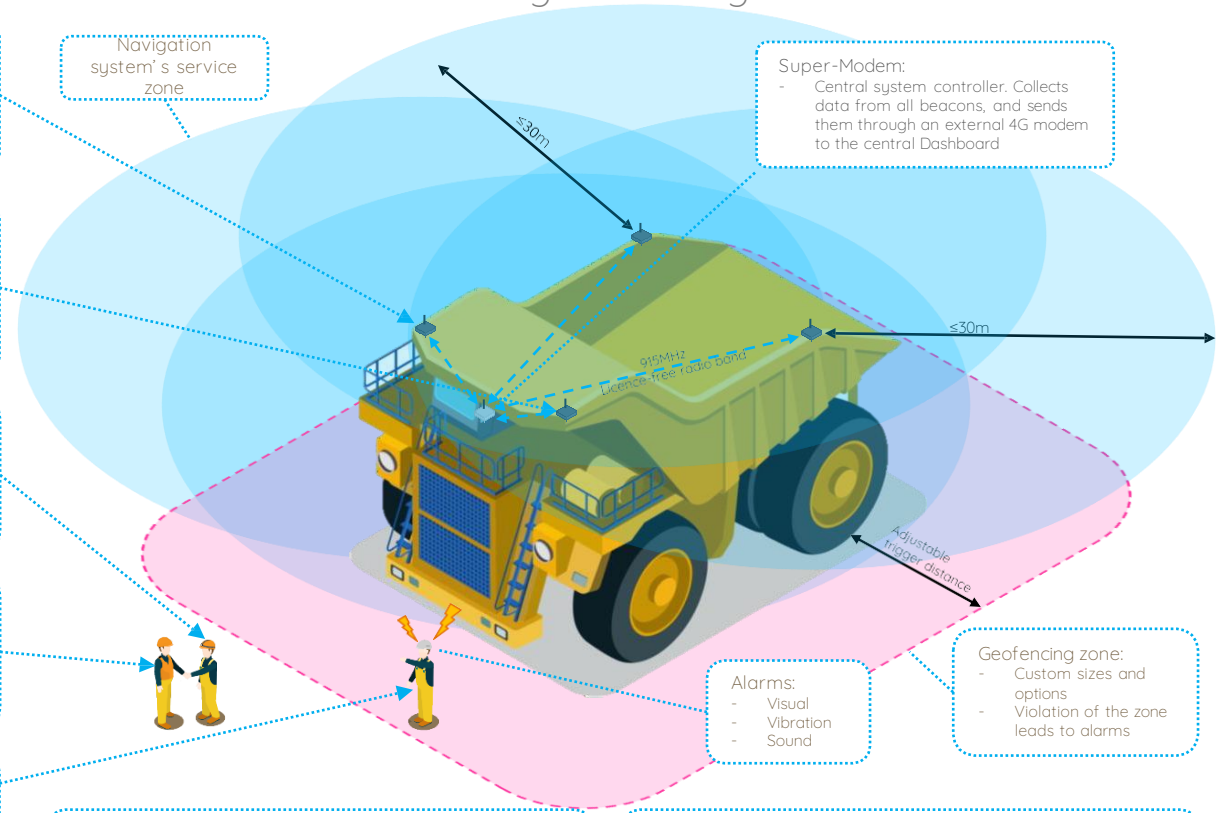
Super-Modem

Marvelmind Headlight

Marvelmind Jacket

Marvelmind Helmet

Navigation system' s service zone



Super-Modem:
- Central system controller. Collects data from all beacons, and sends them through an external 4G modem to the central Dashboard

Alarms:
- Visual
- Vibration
- Sound

Geofencing zone:
- Custom sizes and options
- Violation of the zone leads to alarms

Task:
- Prevent dangerous proximity of AGV and humans
- Prevent AGV-Human Collision

Solution:
- Marvelmind Indoor GPS system installed directly on the AGV, with a mobile geofencing zone

Configuration:
- 4 x Industrial Super-Beacon-Plastic (Placed on AGV)
- N x Marvelmind Headlight (1 per worker, placed on the helmet)
- 1x Super-Modem (Placed on AGV)

Principle of operation:
- The Marvelmind Indoor GPS system, where the AGV is a mobile map, the entrance to the Geofencing zone of which will warn the person and operator about a dangerous proximity, and also, at a critically dangerous proximity, stop the AGV

Result:
- High precision tracking Marvelmind Indoor GPS
- Alarm for workers and equipment drivers
- Recording violations in a CSV file for further analysis
- AGV auto stop (optional)

Marvelmind robotics

Construction safety, people and machinery

Example: 1 excavator and 15 worker

Industrial Super-Beacon
- Fixed to the excavator and connected to the onboard network using Converter-220V-12V- IP67

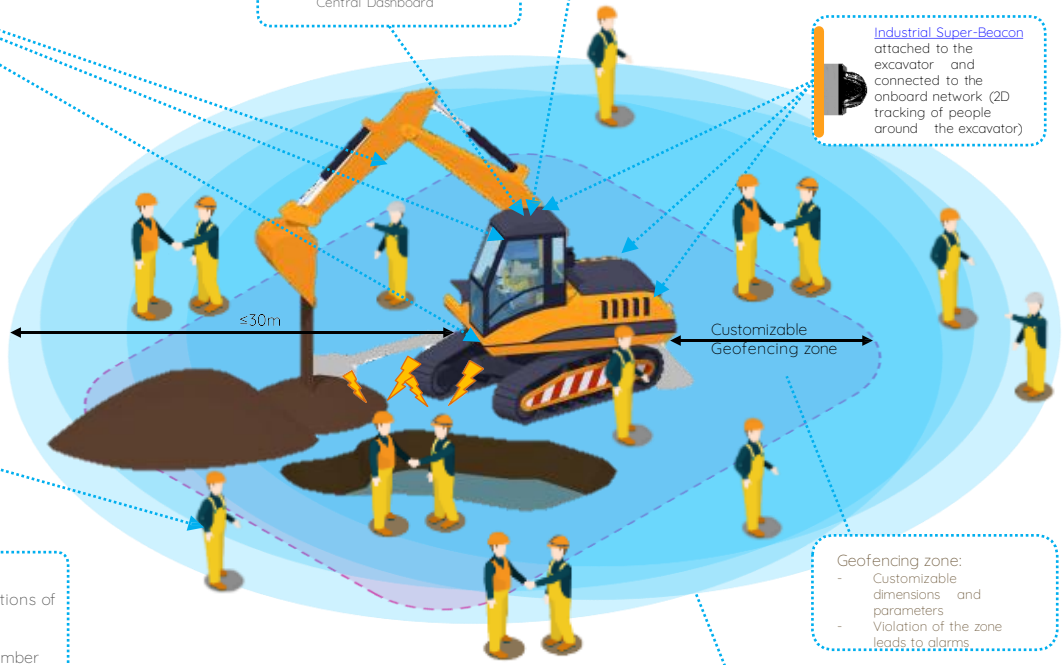
Super-Modem
- Located in the interior of the excavator

Marvelmind Jacket
- Worn by a worker

Task:
- Track employee movements and violations of geofencing zones in 2D during work to improve safety and productivity
- Track the running time as well as the number of movements of the excavator boom in 3D to increase productivity

Super-Modem:
- Central controller of the system. Located in the salon. Collects data from all beacons and sends it via an external 4G modem to the Central Dashboard

4G/5G modem:
- Located in the salon. Sends tracking data and data from the webcam to a remote server



Industrial Super-Beacon attached to the excavator and connected to the onboard network (2D tracking of people around the excavator)

Geofencing zone:
- Customizable dimensions and parameters
- Violation of the zone leads to alarms

Navigation system service area
- 3D tracking of the excavator boom
- 2D tracking of people around you

Configuration for 1 team:
- 9 x Industrial Super-Beacon-Plastic (Located on the excavator)
- 1 x Converter (for connecting stationary beacons and Super-Modem to the onboard excavator network)
- 15 x Marvelmind Jacket (1 per employee)
- 1 x Super-Modem (Located in the cabin of the excavator)
- 1 x Webcam (1 on excavator)
- 1 x 4G/5G modem (1 per excavator)

Principle of operation:
- The Marvelmind Indoor GPS system in this configuration provides 3D tracking of the excavator boom, as well as 2D tracking of people around the excavator within a radius of 30m. The system has customizable Geofencing zones and allows you to warn a person about approaching a danger, such as an excavator boom

Result:
- High-accuracy tracking of Marvelmind Indoor GPS with customizable Geofencing zones
- Alarm to employees and shift Manager
- Transmitting data to the Central server via the REST API using JSOW
- Automatic recording of all safety violations in a CSV file for further analysis

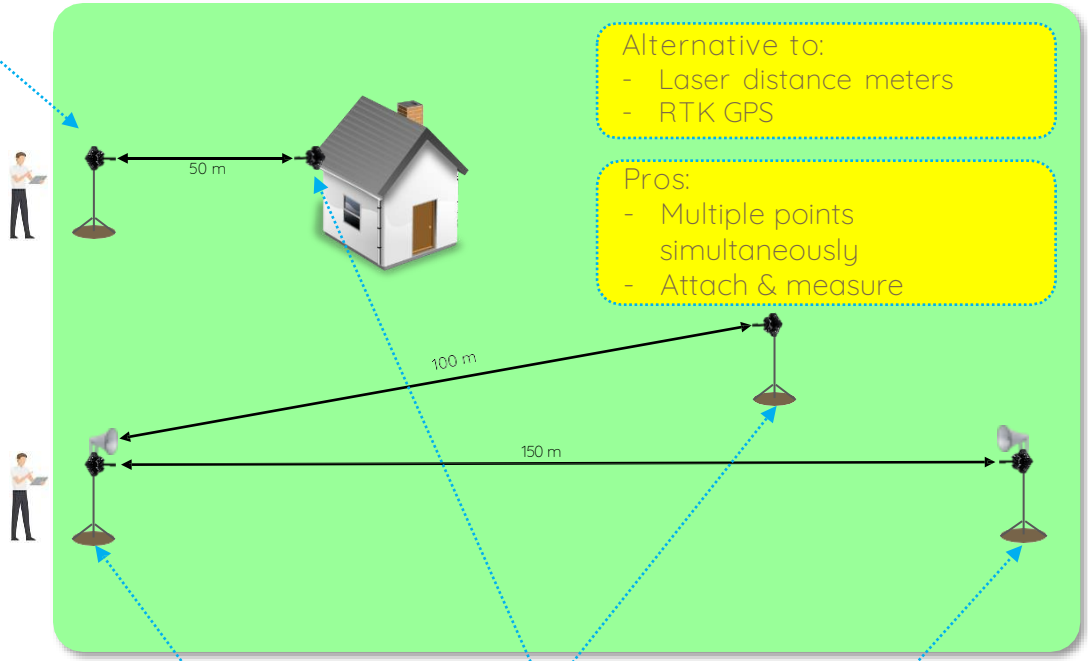
Marvelmind robotics

Precise 1D distance measurements

For construction sites

Receiving beacon with Horn:
- Super-Beacon-Outdoor or
- Beacon Industrial-RX or
- Beacon Mini-RX-Outdoor or
- Ind. Super-Beacon

Task:
- Precise distance up to 100-150m measurements indoor or underground
- Precise distance measurements in fog, dust or through leaves with no direct line of sight, but with sound propagation
- Easy measurements without laborious laser tuning
- Easy to set up and inexpensive alternative to RTK GPS



Alternative to:
- Laser distance meters
- RTK GPS

Pros:
- Multiple points simultaneously
- Attach & measure

Receiving beacon with Horn:
- Super-Beacon-Outdoor or
- Beacon Industrial-RX or
- Ind. Super-Beacon

Transmitting beacon:
- Super-Beacon-Outdoor or
- Industrial Super-Beacon or
- Beacon Industrial-TX

Transmitting beacon with Horn:
- Super-Beacon-Outdoor or
- Industrial Super-Beacon or
- Beacon Industrial-TX

Configuration:
- 1 x Super-Beacon with Horn
- N x Super-Beacons
- 1x Modem

Principles of operation:
- Precise (±2cm) 1D distance measurement from an ultrasound transmitting beacon to an ultrasound receiving beacon using time-of-flight of ultrasound
- Streaming data with 3-16Hz update rate
- Multiple simultaneous trackers
- Various interfaces from UART, RS485 to BT

Result:
- cm-level accuracy 1D distance measurement without laser, for example, when it is not feasible: fog, smog, too bright, leaves, etc.
- cm-level accuracy distance measurement indoor or underground, when RTK GPS is not available or unpractical (expensive)
- High precision tracking Marvelmind Indoor GPS
- CSV file with all recording for analysis
- Automatic recording of all violations in a file for further analysis (optional)

Marvelmind robotics

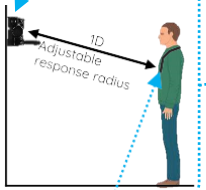
Tracking service staff

An example of a one-floor shopping center

Super-Beacon

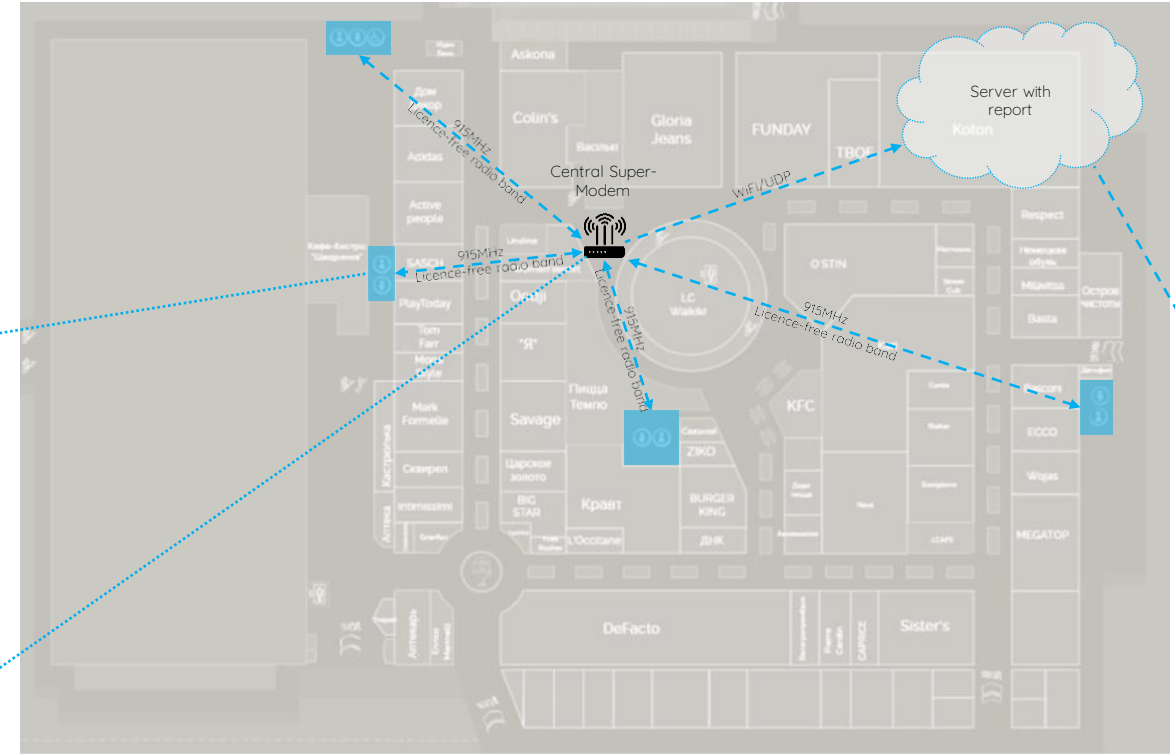
Restroom

Side view



Badge

Super-Modem



Configuration:

- N x Super-Beacon (1 per restroom)
- N x Badge (1 per worker)
- N+1 x Super-Modem (1 per floor + 1 central)

Result:

- Automatic report on movements in the areas of responsibility of service employees (CSV file)
- Auto-fill table (optional)

Reporting Table (Marvelmind)

- The report is generated by the Central Super-Modem, and sent via Wi-Fi to your IP address on request or in a pre- set time (for example, nightly)

Time	Worker 1 (>80%)	Worker 2 (>50%)	Worker 3 (<50%)
8:00-8:15			
11:00-11:15			
20:00-20:15			
21:00-21:15			
22:00-22:15			
23:00-23:15			

Task:

- Tracking service staff
- Performance monitoring

Solution:

- Marvelmind Indoor GPS system for monitoring and analyzing the work of service personnel in 1D configuration

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Non-Inverse Architecture (NIA)

Tuned for single or noisy mobile objects

Stationary beacon 1

Stationary beacons:

- Mounted on walls or ceilings
- Distanced between beacons measured automatically
- Communicate with router wirelessly in ISM/SRD bands

Stationary beacon 2

Key requirement for the system to work - unobstructed sight by a mobile beacon of 2 or more stationary beacons simultaneously (like in GPS)

Mobile beacon:

- Installed on robot/forklift and interacts with it via UART or SPI or I2C or USB
- Receives location update from router up to 25 times per second
- May contain IMU (accelerometer + gyroscope + compass module)

Submaps:

- Advanced feature that allows building independent maps/clusters of beacons in separate rooms and thus covering large buildings (with area of thousands of m2) similar to cellular network coverage

Indoor Navigation System consists of:

- 2 or more stationary beacons
- 1or more mobile beacons
- 1central router

Stationary beacon 4

Distance between beacons-neighbors is up to 30 meters.

Stationary beacon 3

Router/modem:

- Central controller of the system
- Calculates position of mobile beacon up to 25 Hz
- Communicates via USB/virtual UART with Dashboard or robot

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Inverse Architecture (IA)

Tuned for multiple mobile objects and people tracking

Beacon 1(19 kHz)

Stationary beacons:

- Mounted on walls or ceilings
- In inverse system beacons belonging to the same submap should have different ultrasound frequencies (19 & 25kHz or 25 & 31 kHz, for example for 2D tracking)
- Communicate with router wirelessly in ISM/SRD band

Beacon 2 (25 kHz)

Key requirement for the system to work - unobstructed line of hearing/sight by a mobile beacon to 2 or more stationary beacons simultaneously within 30 meters

Submaps:

- Advanced feature that allows building independent maps/clusters of beacons in separate rooms and thus covering large buildings (with area of thousands of m2) similar to cellular network coverage
- In Inverse Architecture every submap must have beacons with non-repeating ultrasound frequency
- Available frequencies: 19/22/25/28/31/34/37/45 kHz

Beacon N (22 or 28/ 34 or 37 or 45 kHz)

Distance between beacons-neighbors is up to 30 meters.

Beacon 3 (31kHz)

Mobile beacon(s):

- Installed on human/robot/drone/forklift and interacts with it via virtual UART over USB
- Contains 3D IMU (accelerometer+gyroscope)
- Beacon's update rate doesn't directly depend on the number of mobile beacons unlike in NIA
- Calculates its location by itself – not by modem
- Recommended distance from mobile beacon to stationary beacons up to 30m

Indoor Navigation System consists of:

- 2 or more stationary beacons
- 1or more mobile beacons
- 1central router

Router/modem:

- Central controller of the system
- Communicates via USB/virtual UART with Dashboard or robot
- Get location data from mobile beacons
- Supports up to 250 beacons

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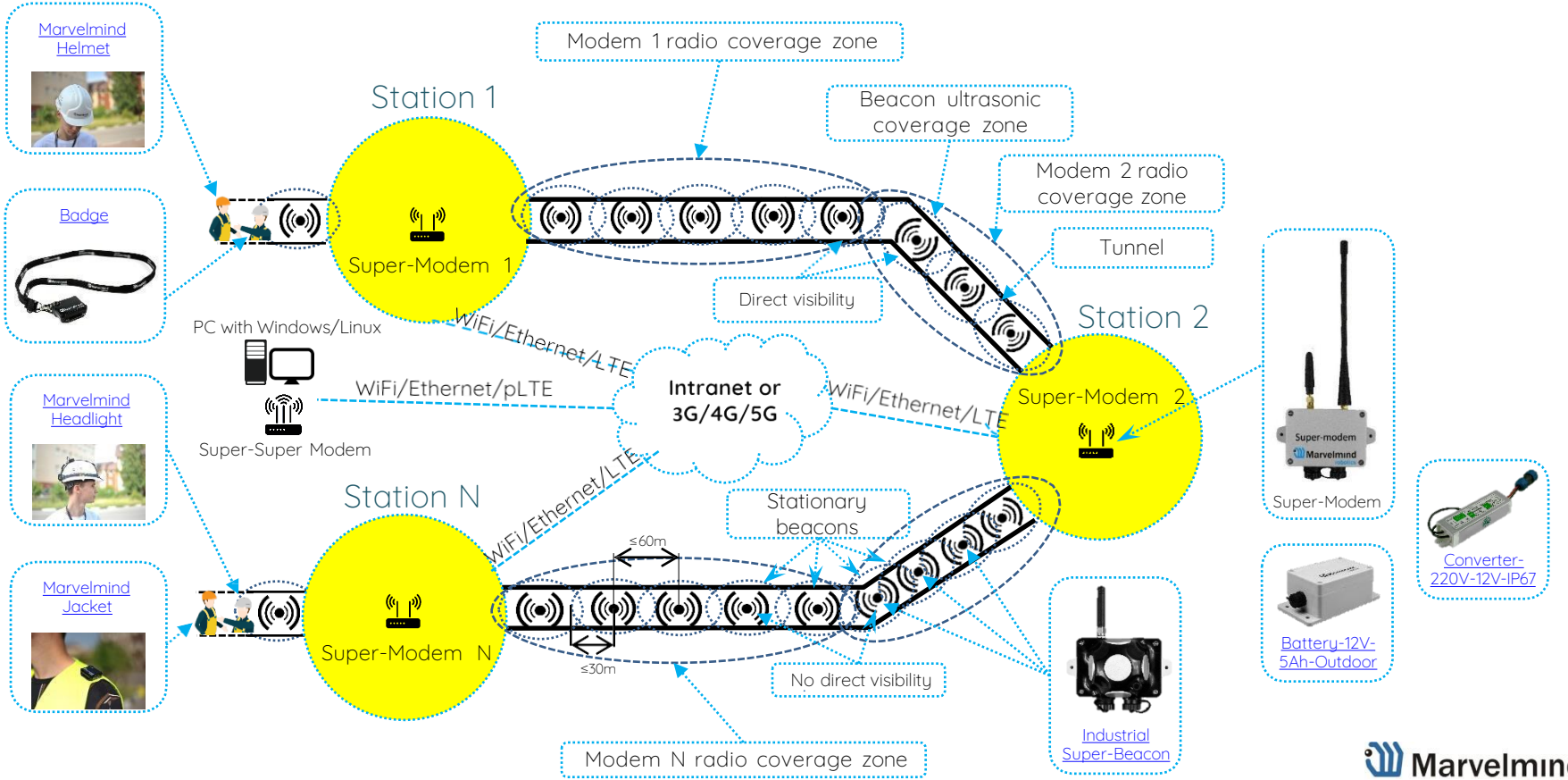
Multi-modem architecture for large networks

Tunnel safety example for underground tracking



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Beacons comparison

	Beacon Mini-RX/Mini-RX-Outdoor	Beacon Mini-TX	Super-Beacon / Super-Beacon-Outdoor	Industrial Super-Beacon-Metal / Industrial Super-Beacon-Plastic	Industrial-RX
Specialty and main use	Small RX-only beacon	Small TX only beacon	Universal dual-use beacon	Heavy-duty outdoor. Support of RS485 (CAN, Exp. Protected - optional)	Heavy-duty outdoor. Support of RS485 (CAN, Exp. Protected - optional)
Mode of operation	RX only	TX only	Dual-use (RX and TX)	Dual-use (RX and TX)	RX only
Range	- Up to 30m with Super-Beacons	- Up to 30m with Super-Beacon	- Up to 30m with Super-Beacons - Up to 100m with Horn	- Up to 30m with Industrial-RX - Up to 100m with Horn	- Up to 30m with Industrial-RX - Up to 100m with Horn
Ultrasonic frequencies	- 19/22/25/28/31/34/37/45 kHz	- 31kHz	- RX: 19/22/25/28/31/34/37/45kHz - TX: Only one frequency at a time	- RX: 19/22/25/28/31/34/37/45kHz - TX: Only one frequency at a time	- RX: 19/22/25/28/31/34/37/45kHz
Radio band	915/868MHz bands. Chinese bands – on request	915/868MHz	915/868MHz bands. Chinese bands (470/779MHz) – on request	915/868MHz bands. Chinese bands (470/779MHz) – on request	915/868MHz bands. Chinese bands (470/779MHz) – on request
Ext. power/int. battery	USB/750mAh	USB/250mAh	USB/1000mAh	Ext. +5V/+6.16V/Ext. battery	Ext. +5V/+6.16V/Ext. battery
Environmental conditions	- Indoor/Outdoor IP67 - t=0..40C[4]	- Indoor - t=0..40C[4]	- Indoor/Outdoor[2] - t=0..40C[4]	- Indoor/Outdoor[2]/Intrinsically Safe[5] - t=-40..60C[4]	- Indoor/Outdoor[2]/Intrinsically Safe[5] - t=-40..60C[4]
Size and weight	47x42x15mm & 25g	35x35x26mm & 19g	55x55x33(64[7])mm & 62/75g	83x58x65mm[8] & 250g	83x58x33mm[8] & 200g
IMU (3D gyroscope + 3d accelerometer)	Yes (6D)	Yes (6D)	Yes (6D)	Yes (6D)	Yes (6D)
Price, EUR	129/149	129	129/149	199/199	179

1) Withstand submersion to water on 1m up to 30m (IPx7 requirements)
2) IP56. Performance during this time is no guaranteed
3) 1D mode: RX4 to RX4 sensors; other sensors are disabled
4) Other power options available upon request
5) Exact type of certification shall be discussed separately
6) Temperature range down to -40C is available with external power supply only and upon request
7) With antenna
8) Sizes without mounting holes
9) 63g without housing

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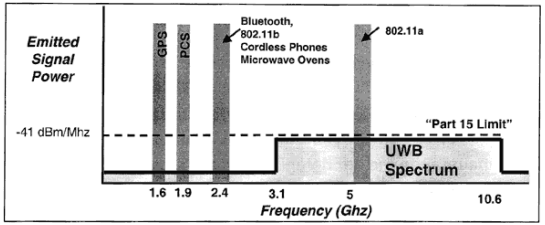
Alternative solutions

Accuracy: 10-30 cm

Compete

UWB
Ultra Wide Band



There are a few dozens of players in UWB globally.
Thus, majority UWB solutions are very similar in performance

Complement/compete

LIDAR
Inertial
Optical flow
Structured light
Laser triangulation
Odometry
GPS
Magnetic field

Accuracy: 2-5 meters

Partially compete

There are hundreds of players in Bluetooth and WiFi navigation. They have the same limitations of any RSSI-based technologies

Accuracy: ±2cm vs. 10-30cm – we are ~10 times more accurate
Price: less expensive than UWB at the same time

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Summary

Marvelmind robotics

Additional slides

Marvelmind Robot v100

An autonomous delivery robot for smart warehousing and industrial applications

Up to 100 kg payload
>16h drive time
4,990 EUR

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Idea

- Fully autonomous, economically viable, and safe delivery robot of small-size goods for warehouse, retail and industrial applications
- Flexible, modular and pragmatic approach
- Predictable and reliable delivery from point A to point B just in time
- Reduced dependence on labor

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Problem to solve

- Usual autonomous guided vehicles (AGVs) are bulky, expensive, complex to integrate, and dangerous to use. If an AGV is not expensive, then it is usually very inflexible in terms of delivery routes (magnetic wires on the floor)
- Many companies simply don't find it economically viable to employ advanced AGVs => the market remains unserved and untapped

Marvelmind robotics

Use case: Autonomous delivery robot

Inexpensive Indoor “GPS” for autonomous navigation

Flexible in size and easy to assemble and maintain frame

QR scanner holder

Very cost efficient – base robot price – 4,990 EUR

Human size

Baskets or boxes for goods

Robot’s base with main controller, battery and multiple sensors, control buttons

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Key benefits of Marvelmind Autonomous Delivery Robot

Fully autonomous delivery:

- Navigation and collision avoidance based on combination of Indoor “GPS” and several other systems and sensors. Solid and reliable autonomous delivery of cargo from point A to point B

Cost efficient solution by design with little or no integration cost:

- Inexpensive Indoor “GPS” + IMU + odometry + optical for navigation and positioning instead of costly LIDARs
- Multiple inexpensive 1D LIDARs as proximity sensors collision avoidance and safety
- No expensive 3rd party elements, no 3rd party SW or licenses or IP – only inhouse solutions

Small size and modular architecture:

- Simple and very customizable frame (“Ikea style”) with possibility to choose between different shelves structure in minutes. Optional additional battery capacity. No dangerous fork
- Suitable for different robot’s height/width/length and cargo boxes/baskets’ sizes

Marvelmind robotics

Use cases

Warehousing:

- Hassle-free delivery of goods between different parts of the warehouse or between storage areas and loading/unloading/assembly areas. Reliable and fast goods delivery from point A to point B, C, D, etc. An assisting person puts loaded baskets or boxes into the robot, press a single physical button B for address B and the rest of inhouse delivery is done fully automatically by the robot

Industrial applications:

- Just in time and reliable delivery on assembly plants (automotive industry, factories, hospitals, chemical or pharmaceutical plants, food industry, etc.) of small and medium size cargo of different size and shape

Competition

- Inexpensive
- Versatile
- Light & Safe

- Only partial competition with AGV – more complementary co-existence. AGVs have different capabilities and serve different needs
- Many regular AGVs players: Kuka/Swisslog, Egemin, AGVE, Ward, JBT etc. Relatively few established competitors in autonomous delivery robots. Some made for own usage only (Amazon/Kiva)
- Very little real competition in small-size delivery robots
- Price and complexity of the total solution is the decisive factor for adoption

Bulky

Dangerous

Expensive

Price: as low as 4,990 EUR instead of 20,000 – 100,000 EUR for regular AGV – 10-20 times less expensive
Size: much smaller and more versatile than regular AGV – human size or smaller
Usage: can be used where regular AGVs are simply not viable

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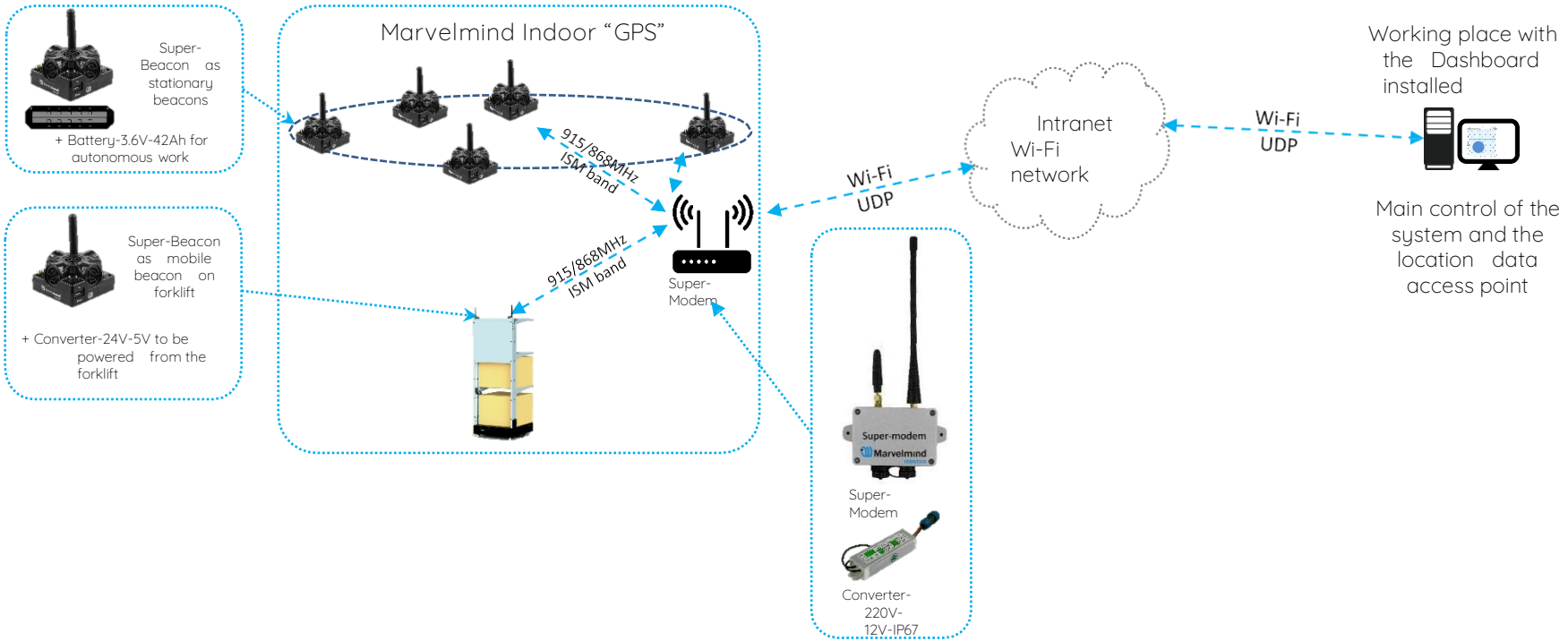
Marvelmind Robot v100 + Indoor “GPS”



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Thank you!

Marvelmind Robotics

Marvelmind OÜ

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