BeanAir

APPLICATION NOTE

Structural Health monitoring on bridges

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DOCUMENT			
Document ID	UM_RF_01	**Version**	V1.3
External reference	UM_RF_01_SpaceW_BeanDevice	**Date**	10/11/2015
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		Project Code	
Document's name	Structural Health monitoring on bridges		

VALIDATION			
Fonction	**Destination**	**For validation**	**For info**
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DIFFUSION			
Fonction	**Destination**	**For action**	**For info**
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UPDATES			
Version	**Date**	**Author**	**Evolution & Status**
V1.0	10/09/2011	Christophe DONTEGREUIL	First version of the document
V1.1	29/04/2012	Maneli PARSY	Technical notes Hyperlink added
V1.2	26/05/2012	Christophe DONTEGREUIL	Videos hyperlink added
V1.3	15/09/2015	Aleksandr Drimitov	• Solar energy harvesting detailed • FFT module detailed • DIN 4150-3 detailed

Contents

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Such changes will, nevertheless be incorporated into new editions of this document.

1. TECHNICAL SUPPORT

For general contact, technical support, to report documentation errors and to order manuals, contact ***BeanAir Technical Support Center*** (BTSC) at:
tech-support@beanair.com

For detailed information about where you can buy the BeanAir equipment/software or for recommendations on accessories and components visit:

www.beanair.com

To register for product news and announcements or for product questions contact BeanAir's Technical Support Center (BTSC).

Our aim is to make this user manual as helpful as possible. Please keep us informed of your comments and suggestions for improvements. BeanAir appreciates feedback from the users.

2. VISUAL SYMBOLS DEFINITION

Visual	*Definition*
	***Caution or Warning** – Alerts the user with important information about BeanAir wireless sensor networks (WSN), if this information is not followed, the equipment /software may fail or malfunction.*
	***Danger** – This information MUST be followed if not you may damage the equipment permanently or bodily injury may occur.*
	***Tip or Information** – Provides advice and suggestions that may be useful when installing BeanAir Wireless Sensor Networks.*

3. ACRONYMS AND ABBREVIATIONS

AES	Advanced Encryption Standard
CCA	Clear Channel Assessment
CSMA/CA	Carrier Sense Multiple Access/Collision Avoidance
GTS	Guaranteed Time-Slot
kSps	Kilo samples per second
LLC	Logical Link Control
LQI	Link quality indicator
LDCDA	Low duty cycle data acquisition
MAC	Media Access Control
PAN	Personal Area Network
PER	Packet error rate
RF	Radio Frequency
SD	Secure Digital
SSD	Smart shock detection
WSN	Wireless sensor Network

4. RELATED DOCUMENTS

In addition to this User manual, please consult the application notes & technical notes mentioned below:

4.1 APPLICATION NOTES

Document name (Click on the weblink)	Related product	Description
AN_RF_007 :" Beanair_WSN_Deployment"	All BeanAir products	Wireless sensor networks deployment guidelines
AN_RF_006 – „How to extend your wireless range"	All BeanAir products	A guideline very useful for extending your wireless range
AN_RF_005 – BeanGateway ® & Data Terminal Equipment Interface	BeanGateway ®	DTE interface Architecture on the BeanGateway ®
AN_RF_003 - "IEEE 802.15.4 2.4 GHz Vs 868 MHz"	All BeanAir products	Comparison between 868 MHz frequency band and a 2.4 GHz frequency band.
AN_RF_002 – "Structural Health monitoring on bridges"	All BeanAir products	The aim of this document is to overview Beanair® products suited for bridge monitoring, their deployment, as well as their capacity and limits by overviewing various Data acquisition modes available on each BeanDevice®.

4.2 TECHNICAL NOTES

Document name (Click on the weblink)	Related product	Description
TN_RF_013 – « OPC configuration »	BeanScape® Premium+	The aim of this document is to help deploying the OPC DA and all associated services.
TN_RF_012– « BeanDevice® battery life in streaming mode »	All the products	The aim of this document is to describe the autonomy performance of the BeanDevice® SmartSensor® and ProcessSensor® product line in streaming packet mode.
TN_RF_011 – « Coexistence of Beanair WSN at 2.4GHz »	All the products	This document aims to highlight the issues affecting co-existence of Beanair WSN (IEEE 802.15.4) in the presence of interference.
TN_RF_010 – « BeanDevice® Power Management »	All the BeanDevice®	This technical note describes the sleeping & active power mode on the BeanDevice®.
TN_RF_009 – « BeanGateway ® management on LAN infrastructure »	BeanGateway ®	BeanGateway ® integration on a LAN infrastructure
TN_RF_008 – "Data acquisition modes available on the BeanDevice®"	All the BeanDevice®	Data acquisition modes available on the BeanDevice®
TN_RF_007 – "BeanDevice® DataLogger User Guide "	All the BeanDevice®	This document presents the DataLogger feature on the BeanDevice®
TN_RF_006 – "WSN Association process"	All the BeanDevice®	Description of the BeanDevice® network association
TN_RF_005 – "Pulse counter & binary Data acquisition on the BeanDevice® SUN-BN"	BeanDevice® SUN-BN	This document presents Pulse counter (ex: energy metering application) and binary Data acquisition features on the BeanDevice® SUN-BN.
RF_TN_003- "Aggregation capacity of wireless sensor networks"	All the products	Network capacity characterization of Beanair Wireless Sensor Networks
RF_TN_002 V1.0 - Current consumption in active & sleeping mode	BeanDevice®	Current consumption estimation of the BeanDevice in active and sleeping mode
RF_TN_001 V1.0- Wireless range benchmarking	BeanDevice®	Wireless range benchmarking of the BeanDevice®

5. AIM OF THE DOCUMENT

Bridges, which are the key components of any transportation system, have expected life cycles as long as 50 or 100 years, it is however not uncommon to see even older structures which are still in service. During its long service life a bridge would be subject to aging processes, harsh environmental conditions and excessive loads, leading to deterioration. Consequences of impaired physical condition can be as severe as the collapse of the structure, causing great financial loss or even casualties, but even major protective maintenance and upgrading works or replacement of the bridge are expensive and troublesome. Thus, it is important to have updated information on structural condition and performance of bridges in order to early detect any worrying signs of decline and undertake protective countermeasures. Transportation infrastructure authorities have long recognized the need to keep their bridges healthy and to this end have implemented various inspection and management programs. The current health monitoring practice is primarily based on visual inspection. However, due to high manpower demand such inspections cannot be performed frequently. Other drawbacks of visual inspection based condition assessment include inaccessibility of critical parts of the structure and lack of information on actual loading. These shortcomings lead to subjective and inaccurate evaluations of bridges safety and reliability. As a result some bridges may be retrofitted or replaced, while in fact they are sound; on the other hand, existing damages in other bridges may not be identified until they become expensive to repair or dangerous for structural integrity. An alternative to the periodic visual inspection can be continuously operating instrumented structural health monitoring (SHM) systems. The recent developments in sensor technology, especially when wireless technology is considered have opened up new gates in terms of health monitoring and preemptive fault detection. Beanair®'s wireless sensor technology offers great reliability, versatility, maintainability and easy to deploy and configure technology.

The aim of this document is to overview Beanair® products suited for bridge monitoring, their deployment, as well as their capacity and limits by overviewing various data acquisition modes available on each BeanDevice®.

6. SMARTSENSOR PRODUCTS PRESENTATION

The Smartsensor® product line is declined as the following:

- ✓ ***BeanDevice® AX-3D & AX-3D XRange***: 3-axis wireless accelerometer for vibration measurement
- ✓ ***BeanDevice® AX-3DS***: 3-axis wireless accelerometer for shock measurement
- ✓ ***BeanDevice® HI-INC & HI-INC XRange***: 1 or 2-axis wireless inclinometer for tilt measurement

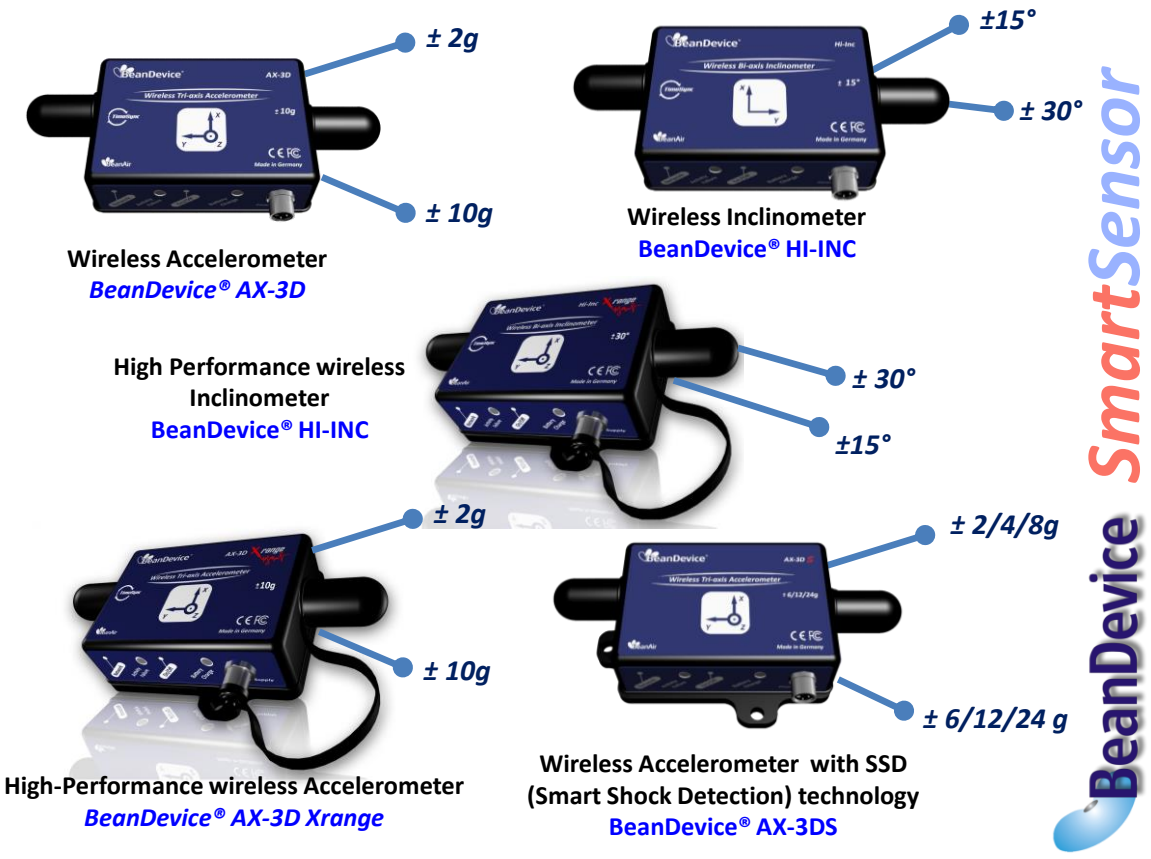


Figure 1: SmartSensor Products line

Click here to see BeanDevice® AX-3D video

Click here to see BeanDevice® AX-3D XRange video

Click here to see BeanDevice® HI-INC video

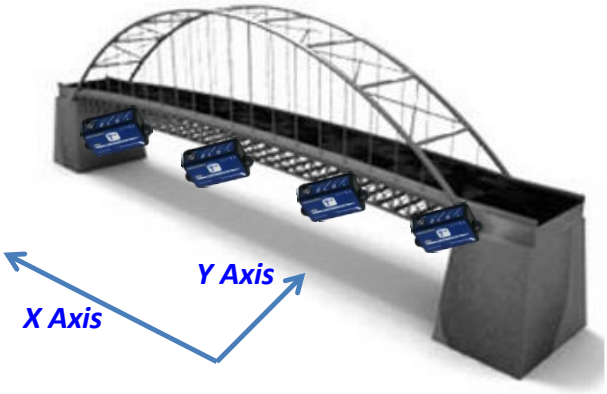
Click here to see the video of the BeanGateway®

7. BRIDGE MONITORING USING WIRELESS SMART SENSORS

7.1 TILT MONITORING

Figure 2: Tilt monitoring

The following pictures shows how the BeanDevice® can be mounted on a bridge. In this particular case the mounting was done by using aluminum coil tape and epoxy glue.



Tilt Measurement on bridge (max measurement range +/-1,5°)

7.1.1 BeanDevice® HI-INC configuration

BeanDevice® HI-INC configuration for Tilt measurement on a Bridge		
Recommended BeanDevice® version	**BeanDevice® HI-INC** ±15° , adhesive mounting **BeanDevice® HI-INC Xrange** ±15°, screw mounting	
Data acquisition mode used	**Slow monitoring**	LDCDA (Low Duty Cycle Data Acquisition) with a duty cycle of: 10 seconds to 1 hour
	Fast monitoring	Streaming Packet mode : 1 Hz to 40 Hz
Maximum inclination range	± 1.5°	
Maximum wireless range	300 to 500 meters The user can extend the wireless range by using a high gain and directional antenna on the BeanGateway®.	
Battery Autonomy	**Slow monitoring**	2 to 6 months
	Fast monitoring	18hours maximum
Number of axis	1 or 2	
Number of BeanDevice® on the same wireless sensor network	**Slow monitoring**	45 maximum
	Fast monitoring	Please refer to the Technical Note: ***"TN_RF_003 Wireless Network Capacity"***

Table 1 : BeanDevice® HI-INC configuration

7.2 VIBRATION MONITORING

Figure 3: **Vibration Monitoring**

Vibration measurement on the pillar

7.2.1 BeanDevice® AX-3D and BeanDevice® AX-3D Xrange configuration

BeanDevice® AX-3D & BeanDevice® AX-3D Xrange configuration for vibration measurement on a Bridge		
BeanDevice® version used	BeanDevice® AX-3D, adhesive mounting BeanDevice® AX-3D, screw mounting	
Measurement range	±2g or ±10g or ±13g	
Data acquisition mode used	Streaming Packet mode with a sampling rate of 200 Sps (samples per second) maximum	
Maximum Vibration range	± 2g	
Maximum wireless range	300 to 500 meters The user can extend the wireless range by using a high gain and directional antenna on the BeanGateway®.	
Battery Autonomy	***Fast monitoring***	18 hours maximum The user can extend the battery autonomy by adding an external battery and a solar panel.
Number of axis	3 axis	
Number of BeanDevice® on the same wireless sensor network	4, if the sampling rate is 200 Sps on each BeanDevice (3 axis activated) Please refer to the Technical Note: ***TN_RF_003 Aggregation capacity of wireless sensor networks***	

Table 2 : BeanDevice® AX-3D and AX-3D Xrange configuration

7.3 SINKING, SHOCK AND CRACK DETECTION ON BRIDGE

Figure 4: **Sinking, Shock and Crack detection on Bridge**

The BeanDevice® AX-3DS can be used for detecting a shock event during a train passage on a bridge. This product is ideal for analyzing the shock profile on the bridge foundation.

7.3.1 Advantages of SSD Technology (Smart shock Detection)

The BeanDevice® AX-3DS offers the following advantages:

<table>
<tr><td>SSD (Smart shock detection) Technology</td><td colspan="2">The BeanDevice® will wake up when a shock threshold is detected. The user can fix by himself the shock threshold and time hysteresis.
For further information about the SSD (Smart Shock Detection) measurement mode, read the technical note TN_RF_008 "Data acquisition modes available on the BeanDevice®"</td></tr>
<tr><td>Ultra Low Power wireless sensor</td><td colspan="2">Power Consumption in Sleeping step :
Power Consumption in sleeping mode with SSD (Smart Shock Detection) activated:</td></tr>
<tr><td></td><td>Accelerometer Bandwidth during Sleeping Mode</td><td>BeanDevice® Power Consumption</td></tr>
<tr><td></td><td>0 Hz</td><td>8µA</td></tr>
<tr><td></td><td>0,5 Hz</td><td>21 µA</td></tr>
<tr><td></td><td>2Hz</td><td>50 µA</td></tr>
<tr><td></td><td>1 Hz</td><td>31 µA</td></tr>
<tr><td></td><td>5Hz</td><td>78 µA</td></tr>
<tr><td></td><td>10Hz</td><td>130 µA</td></tr>
<tr><td></td><td>50 Hz</td><td>302 µA</td></tr>
<tr><td></td><td>100 Hz</td><td>308 µA</td></tr>
<tr><td></td><td>400 Hz</td><td>343µA</td></tr>
<tr><td></td><td>1000 Hz</td><td>413 µA</td></tr>
<tr><td>False alarm management</td><td colspan="2">For avoiding false alarms, the user can fix by himself the time hysteresis.</td></tr>
</table>

Table 3 : SSD (smart shock detection) technology

7.3.2 BeanDevice® AX-3DS configuration

BeanDevice® AX-3DS configuration for Shock measurement on a Bridge	
BeanDevice® technology used	BeanDevice® AX-3DS
Data acquisition mode used	SSD (Smart Shock Detection) measurement mode. The BeanDevice® will wake up if a shock profile is detected.
Maximum wireless range	300 to 500 meters The user can extend the wireless range by using a high gain and directional antenna on the BeanGateway®.
Number of axis	3 axis
Number of BeanDevice® on the same wireless sensor network	20 to 50 BeanDevice®

Table 4 : BeanDevice® AX-3DS configuration

8. WIRELESS SENSOR NETWORK TOPOLOGY

8.1 OUT OF THE BOX WSN WITH AN ETHERNET LINK

The most basic/minimal WSN consists in deploying a local network that can be monitored through a local PC server/ embedded PC. In this case the PC is either directly connected to the BeanGateway® (in case of a mono-gateway architecture) or to a switch that is connected to multiple gateways through an Ethernet link.

Figure 5: Network Topology with 1 BeanGateway® connected to the BeanScape®

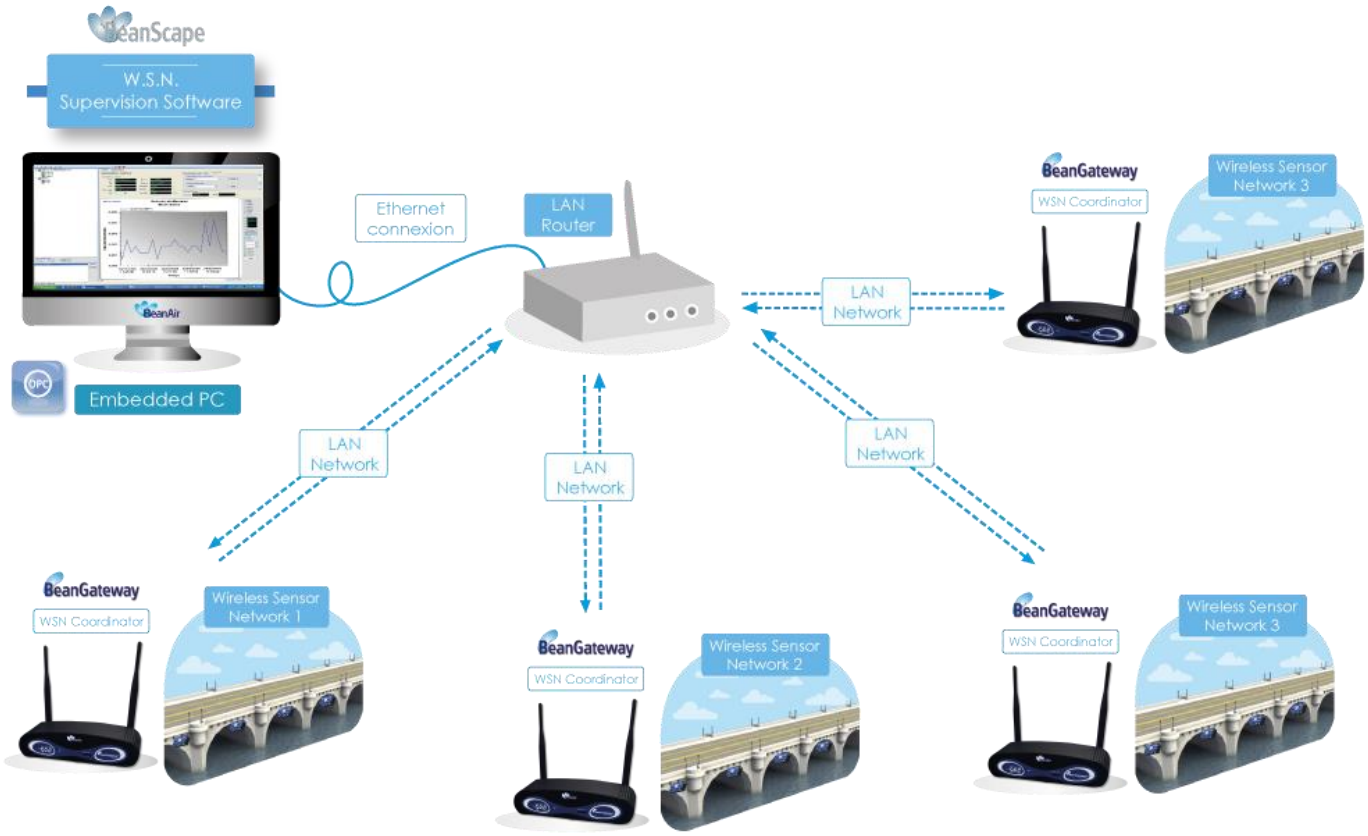


Figure 6: Network Topology with several BeanGateway® connected to the BeanScape®

For further information about the LAN configuration, please read the technical note TN_RF_009 "BeanGateway® management on a LAN infrastructure".

8.1.1 Hardware Requirements

Embedded PC	Use a ruggedized "Embedded PC" with Windows Embedded or Windows XP software. The BeanScape® is not compatible with Linux or Ubuntu OS.
BeanGateway® version	Outdoor version of the BeanGateway® with Ethernet link

8.1.1 Network architecture performances

FEATURES	
Local /Cloud supervision software	BeanScape®(Local supervision software)
Network Reliability	High
Network installation complexity	Low
Compatibility with streaming packet and SSD Data acquisition mode	Yes

8.2 WIRELESS SENSOR NETWORKS COMING WITH 3G LINK

8.2.1 Hardware Requirements

The 3G network is well suited for high rate data transmission (Streaming Packet mode). The minimum requirements for implementing a 3G connection are:

3G Gateway	***TECHNOLOGY*** • HSUPA with fallback to: HSDPA, UMTS, EDGE ***Bands*** Tri-Band UMTS/HSDPA/HSUPA: 850, 1900, 2100 MHz Or Quad-Band UMTS/HSDPA/HSUPA: 850, 900, 1900, 2100 MHz ***HOST INTERFACES*** Ethernet: 10/100 BASE-T RJ-45 ***APPLICATION INTERFACES*** TCP/IP, UDP/IP, DHCP, HTTP, SNMP, SMTP, SMS, MSCI
ADSL Modem	ADSL Modem with NAT Configuration software
BeanGateway®	Ethernet version of the BeanGateway®

For further information about the 3G Network configuration, please read the technical note TN_RF_009 "BeanGateway® management on a LAN infrastructure".

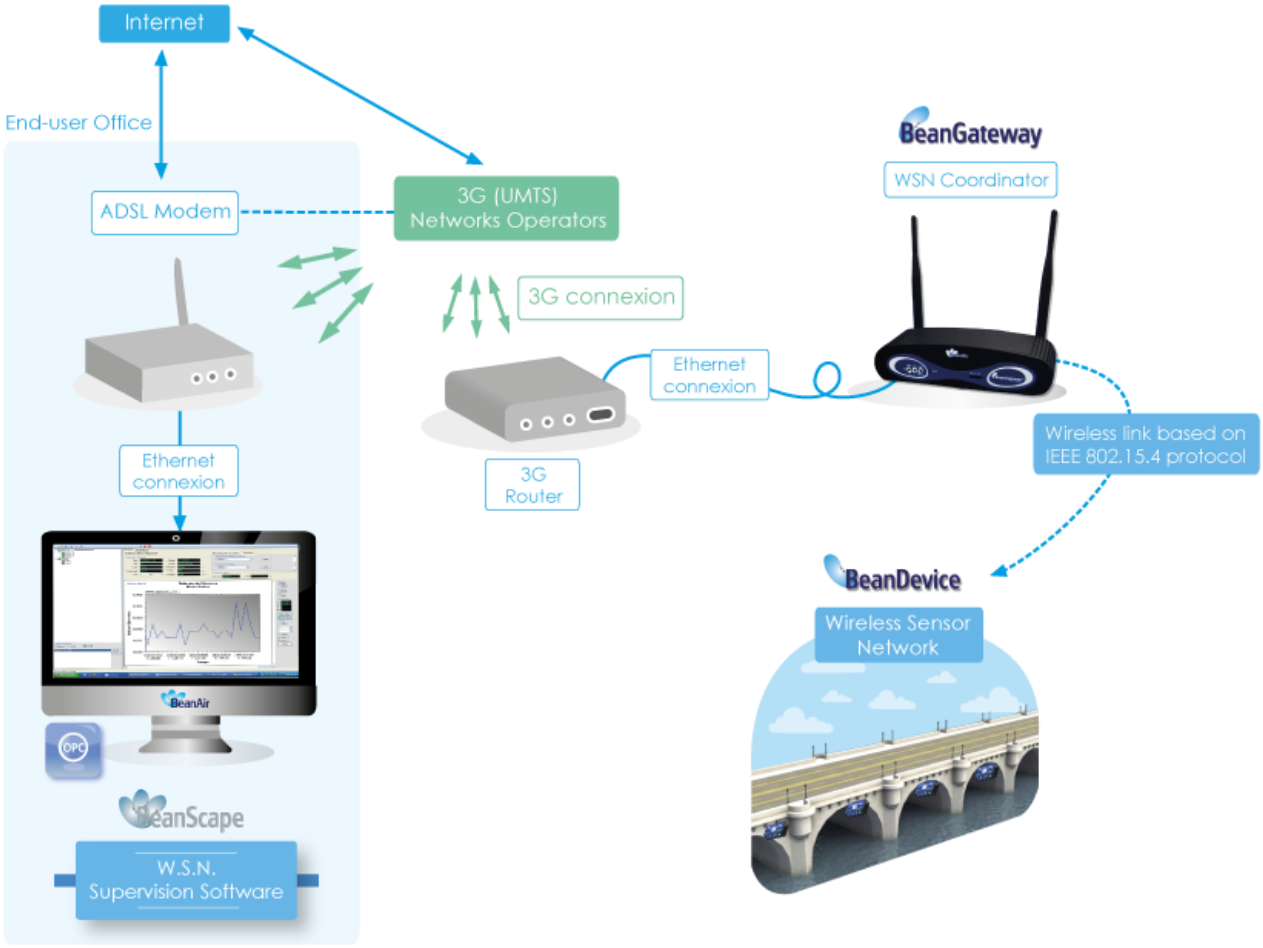


Figure 7 : WSN with 3G link

8.2.2 Network architecture performances

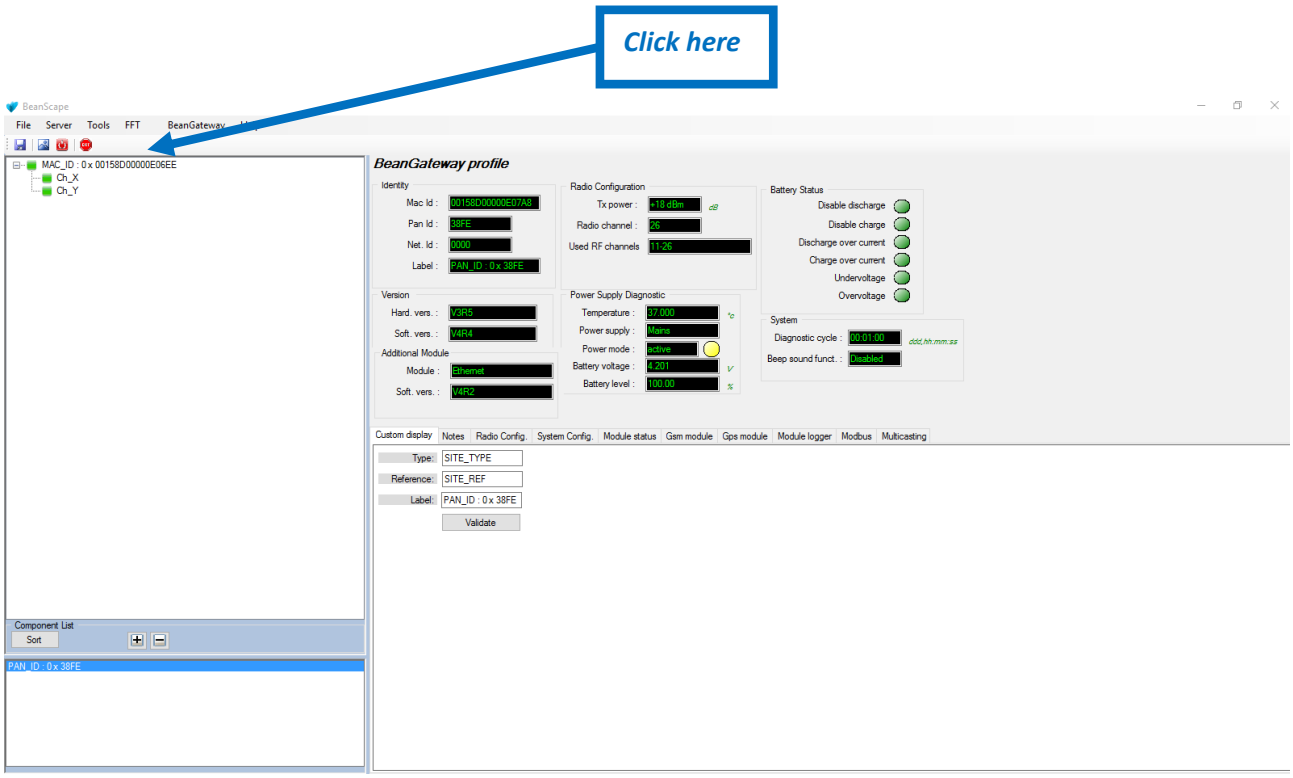
FEATURES	
Local /Cloud supervision software	Local (BeanScape®)
Network Reliability	***Low*** : Beanair cannot make a guarantee the 3G Quality of Services (QOS)
Network installation complexity	High
Compatibility with streaming packet and SSD Data acquisition mode	Yes

9. FFT (FAST FOURIER TRANSFORM) WAVEFORM ANALYSIS MODULE

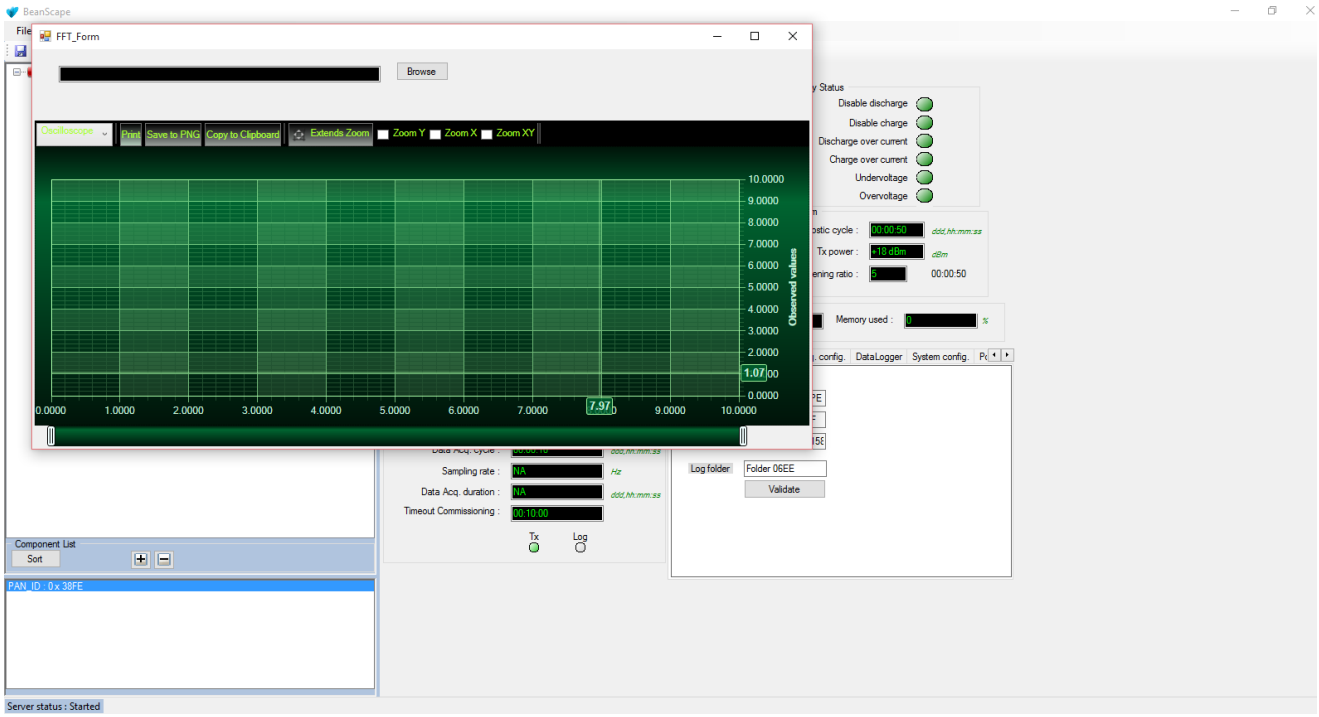
The Fast Fourier Transform (FFT) resolves a time waveform into its sinusoidal components. The FFT takes a block of time-domain data and returns the frequency spectrum of the data. The FFT is a digital implementation of the Fourier transform. Thus, the FFT does not yield a continuous spectrum. Instead, the FFT returns a discrete spectrum, in which the frequency content of the waveform is resolved into a finite number of frequency lines, or bins.

BeanScape® (Basic, Premium and Premium+ version only) software is provided with FFT waveform analysis module.

FFT (Fast Fourier transform) module is only compatible with "Streaming Packet" measurement mode.

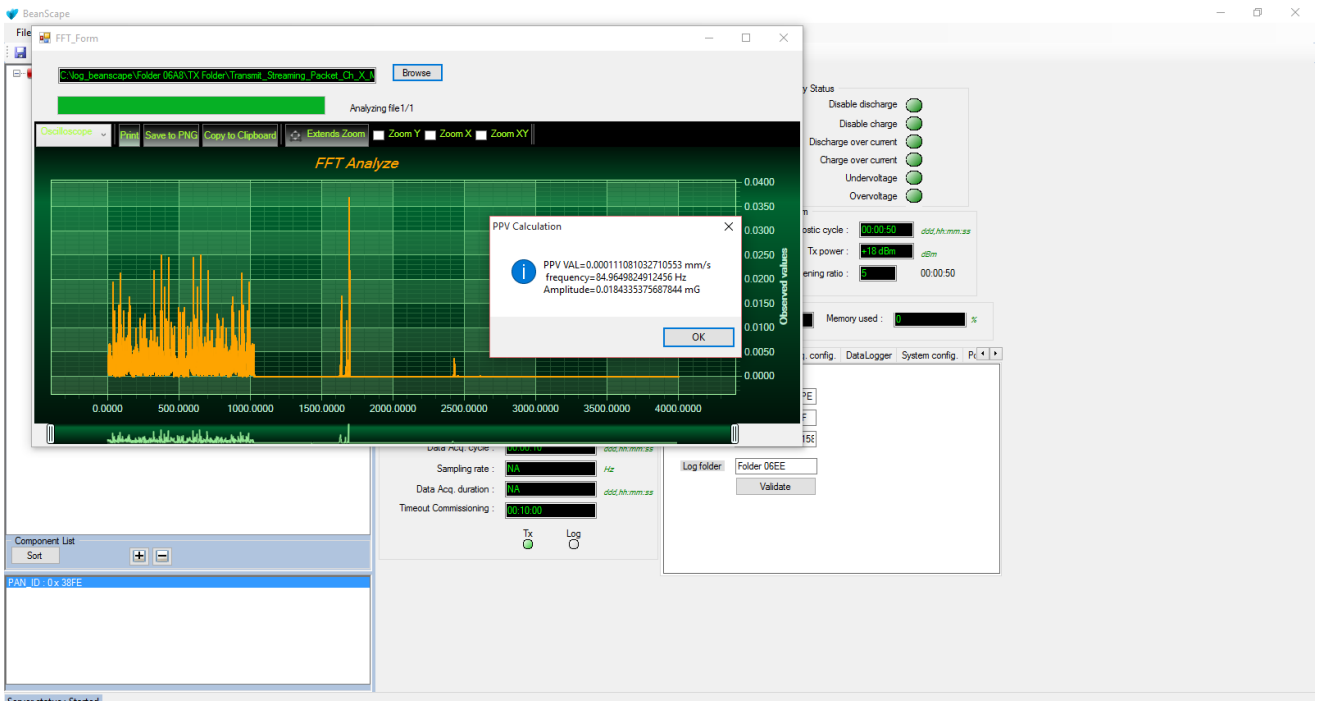


A new window will open:



Click on browse and import file containing the logged measurement, the result will be:

- Power spectral density and a new window displays
- PPV (peak particle velocity) calculation: PPV value in mm/s, Frequency, Amplitude



[Watch Fast Fourier Transform Analysis Video]

10. ABOUT DIN 4150-3 STANDARD STRUCTURAL VIBRATION

DIN4150-3 standard specifies a method of measuring and evaluating the effects of vibration on structures designed primarily for static loading. It applies to structure which do not need to be designed to specific standards or codes of practice as regards dynamic loading.

This standard gives guideline values which, when complied with, will not result in damage that will have an adverse effect on the structure's serviceability. In some cases, guideline values for a simplified evaluation are also given.

10.1 EVALUATING EFFECTS OF SHORT-TERM VIBRATION

Type of structure	*Guideline values for velocity, vi in mm/s Vibration at the foundation at a frequency of*			*Vibration at horizontal plane of highest floor at all frequencies*
	1 Hz to 10 Hz	*10Hz to 50 Hz*	*50 Hz to 100 Hz*	
Buildings used for commercial purposes, industrial buildings, and buildings of similar design	20	20 to 40	40 to 50	40
Dwellings and Buildings of similar design and/or occupancy	5	5 to 15	15 to 20	15
Other structures	3	3 to 8	8 to 10	8

Table 5: Guideline values for vibration velocity to be used when evaluating the effcts of short-term vibration on structure

At frequencies above 100 Hz, the values given in this column may be used as minimum values

11. HOW TO EXTEND YOUR BEANDEVICE® BATTERY LIFE

For further information about the BeanDevice® battery life please read the technical note TN_RF_002 "Current consumption in active & sleeping mode on BeanDevice® products (wireless sensors)".

11.1 EXTERNAL POWER SUPPLY

Caption:

Pwr+ : power supply 8-28 V DC

Gnd : electrical ground

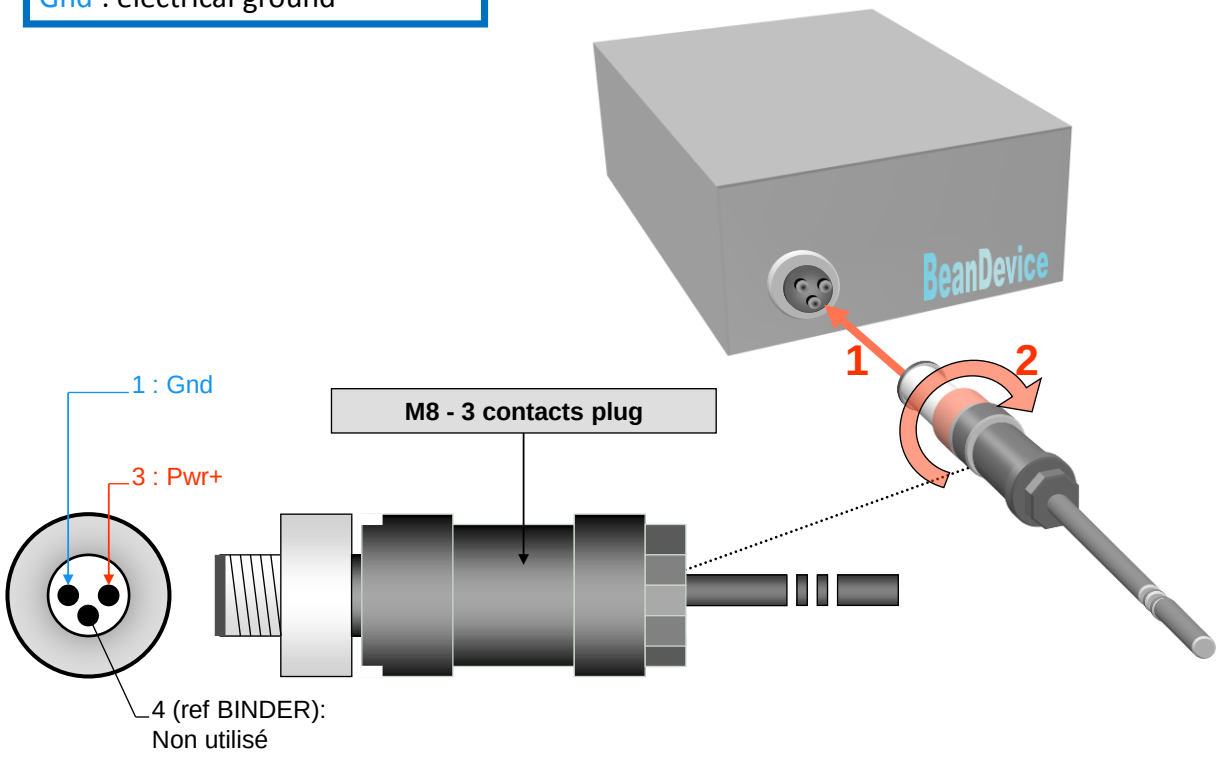
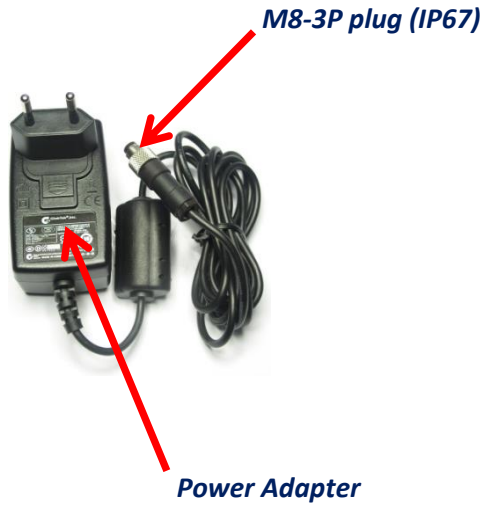


Figure 8: External Power Supply

The BeanDevice® can also be powered by an AC-to-DC adapter ***8-28Volts***. The power adapter can be used for recharging Lithium-Ion battery or to power supply continuously the BeanDevice®.
A M8-3Pins standard plug is used for connecting the power adapter to the BeanDevice®.



Only the M8 plug is fully sealed, the power adapter is not sealed.

11.2 SOLAR PANEL KIT

You can use a solar panel kit:

- ✓ ***Battery Charge controller***
- ✓ ***High rate valve regulated sealed lead acid (VRLA)*** : these batteries have been developed for long term operation in harsh environments
- ✓ ***Solar Panel:*** the size of the solar panel depends on the average consumption of the BeanDevice®

You can buy a Solar Panel Kit from these providers:

www.tyconpower.com

http://www.solar-electric.com/chco.html

http://www.futurlec.com/Solar.shtml

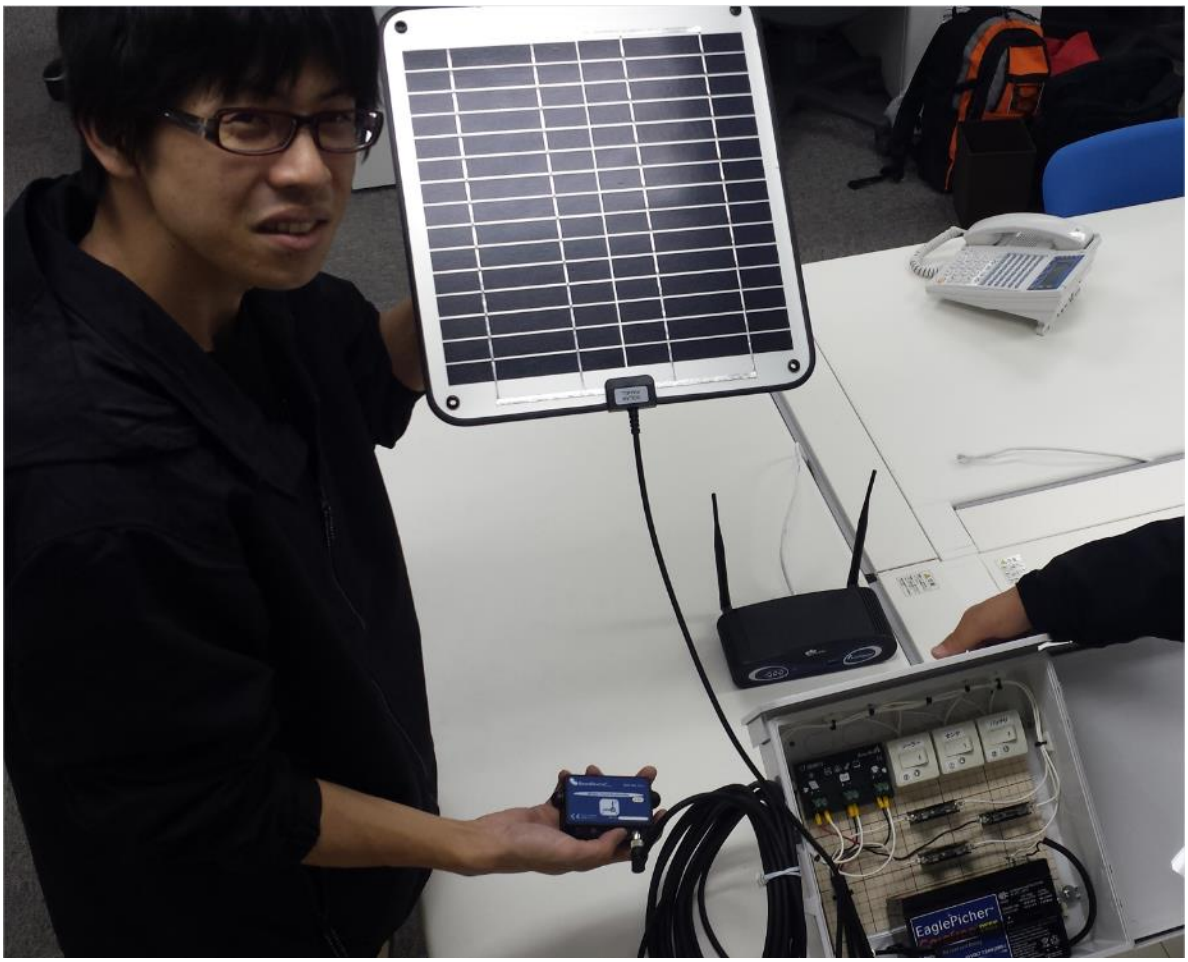


Figure 9: ***An example of solar panel kit***