C.L.E.E.N

D525

Report on the full specifications for Intelligent wireless acquisition system

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1. Scope of this Work

The scope of this study is to draft the technical principles and preliminary design topics that will be the foundation of a first complete design specifications of ***Vibrometric Wireless Seismic Array (VWSA)*** *system*.

2. Introduction

Large-scale underground storage of CO2 has the potential to play a key role in reducing global greenhouse gas emissions. Typical underground storage reservoirs would lie at depths of 1000m or more and contain tens or even hundreds of millions of tonnes of CO2. A likely regulatory requirement is that storage sites would have to be monitored both to prove their efficacy in emissions reduction and to ensure site safety. A diverse portfolio of potential monitoring tools is available, some tried and tested in the oil industry, others as yet unproven. Shallow-focussed techniques are likely to be deployed to demonstrate short-term site performance and, in the longer term, to ensure early warning of potential surface leakage. Deeper focussed methods, notably **time-lapse seismic**, will be used to track CO2 migration in the subsurface, to assess reservoir performance and to calibrate/validate site performance simulation models.

In CO2 monitoring, the purpose of seismic technique is to determine the **changes in seismic properties (mostly acoustic impedance) that resulted from CO2 injection** by comparing the surveys among time-lapse seismic data set.

3. Present and Near Future Challenges in Time-Lapse Seismic Surveys

In Time-Lapse Seismics data is being acquired with an additional parameter of "time" as the 4th dimension of the existing 3D data acquisition system. This is called 4D data acquisition. Time-lapse or 4D seismic surveys use the difference between surface seismic surveys to measure production and reservoir properties periodically during the life of the reservoir. Fluid changes and/or changes in reservoir pressures determine significant differences seen between the survey results.

As the seismic industry made one breakthrough after another during its history, it also created new challenges for itself. Now we record not just p-waves but also converted s-waves for a wide range of objectives. Using the multi-component seismic method, commonly known as the 4-C seismic method, we are now able to see through gas plumes caused by the reservoir below. We are able to sometimes better image the sub-salt and sub-basalt targets with the 4C seismic method. Using the converted s-waves, we are able to detect the oil-water contact, and the top or base of the reservoir unit that we sometimes could not delineate using only p-waves.

Surface Data Acquisition: In surface acquisition, a shot is fired (i.e., energy is transmitted) and reflections from the boundaries of various Lithological units within the sub-surface are recorded at a number of fixed receiver stations on the surface. These geophone stations are usually in-line although the shot source may not be. When the source is in-line with the receivers – at either end of the receiver line or positioned in the middle of the receiver line – a two-dimensional (2D) profile through the earth is generated. If the source moves around the receiver line causing reflections to be recorded form points out of the plane of the in line profile, then a three-dimensional (3D) image is possible (the third dimension being distance, orthogonal to the in-line receiver-line). The majority of land survey effort is expended in moving the line equipment along and / or across farm fields or through populated communities. Hence, land operations often are conducted only during daylight thus making it a slow process.

4. Seismic Data Acquisition Challenges

Seismic data acquisition projects are subject to the modern project management approach as any other engineering projects. Thus, the traditional three key constraints; “Cost”, “Time” and “Scope” are applicable in the management of a seismic survey project.

As earlier observed, the scope of a seismic survey is clearly broader due to the development from 2D to 3D and 4D (time-lapse) seismic surveys. This dictates the **significant increase of seismic data volume to be acquired**, transmitted, stored and processed. Other important factors contributing to this data volume increase are: the increased resolution need and sampling rate of the data acquisition.

Data quality

In seismic surveys, **increasing productivity**, or the number of seismic traces recorded in a given time, is always an important challenge. There are multiple factors which limits the productivity:

- Initial deployment of the field line equipment and re-deployment of the receiver lines in case of large scale / high receiver density projects;
- Idle times due to: time necessary to write the data on the disk if the data transmission is not real-time or near real-time, movement of the seismic source and/or of the receiver lines, batteries replacement for the field units, equipment failures.

Time-lapse surveys add to these traditional challenges the need for **repeatability** of multiple seismic surveys conducted at the same place:

- **Repeatability** of source and receiver locations;
- **Repeatability noise** (which depends on the accuracy with which successive surveys can be matched), rather than resolution, may be the key parameter controlling detection thresholds. Wellbore seismic methods, such as VSP and cross-hole seismics, provide higher resolution of the near-borehole environment with direct measurement of velocity and signal attenuation (both key indicators of fluid saturation) providing finer-scale information complementary to the surface methods

“Many of the world’s hydrocarbon reserves are to be found onshore, and equally important, many of the world’s reserves are located in carbonate reservoirs. Two factors inhibit the application of 4-D seismic methods in these geographic areas and geologic environments. First, the bulk strength of carbonate rocks is higher than most sandstones, resulting in a relatively weak time-lapse signal. Second, high-amplitude near surface-generated noise has historically masked signal but can now be attenuated through the implementations of single-sensor seismic acquisition techniques onshore such as Q-Land, enhancing our ability to detect weak low-amplitude time-lapse signals.

Data delivery is important in seismic reservoir monitoring, as each seismic survey represents a snapshot of reservoir conditions at a moment in time. In-field or onboard processing is speeding the delivery of time-lapse seismic surveys, enabling time-lapse difference estimates of reservoir production or injection to be delivered within days of seismic survey completion.” – see http://www.epmag.com/EP-Magazine/archive/Time-lapse-seismic-technology-Past-Present-Future_4298

5. Concepts for Continuous Monitoring

(Source: Subsurface Monitoring of Geological CO2 Storage: Jerry M. Harris, Professor, Geophysics; Youli Quan, Research Associate, Geophysics;David Wynn, Jonathan Ajo-Franklin, Chunling Wu, Jaime Urban, O. Martins Akintunde, Chun-tang Xu, Graduate Research Assistants, Stanford University)

In this chapter, we aim to bring forward the complexity of the sensor array deployments for the monitoring of Geological CO2 Storage that, consequently, lead to stringent technological challenges that Vibrometric took into the consideration when designing the Vibrometric Wireless Seismic Array (VWSA). The complexity presented will show the necessity of wireless construction, as the ease of deployment different structure arrays will be a must in the viability, in commercial terms, of such projects.

We expect the storage site to experience 3-4 distinct phases of operations: Site characterization, injection and post-injection, and closure as illustrated in Figure 1. Moreover, monitoring must be planned for the varying needs of these different phases and must adapt to unpredictable reservoir conditions. The cost of monitoring should decrease with time and eventually go to zero as illustrated, though the details will vary from one site to another. Moreover, the subsurface response to CO2 is never fully predictable; therefore, in order monitor the pathways properly, we may need to adjust the data acquisition configuration from time to time.

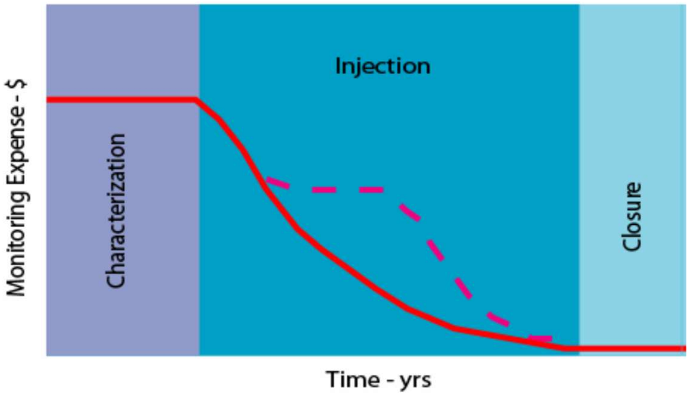


Figure 1: Three phases of a storage project. The monitoring costs should decrease with time. The cost curves (red and purple) represent two possible procedures.

Monitoring builds from the high-resolution baseline model that is developed during the characterization phase.

A monitoring strategy must contribute to the safety case that will be required for licensing the site. Such monitoring activities are expected to be most active during the injection phase, decline during post-injection, and possibly end altogether during the closure phase as illustrated by the solid red line in the figure above. If, however, leaks are detected or suspected, monitoring resources must be available to address identification and mitigation of possible containment problems, as illustrated by the dash red line in Figure 3.1. In fact, closure may be defined by the significant curtailment of monitoring activities.

For these reasons, monitoring serves two important purposes: (1) provides advance warning of imminent problems such leaks; and (2) confirms predicted reservoir behavior and provides data for optimizing efficiency. To this end, a practical subsurface monitoring plan should utilize information from other sources such as predictions from flow simulators and observations from wells. These monitoring objectives can be met by combining two complementary types of subsurface imaging: (1) Reconnaissance surveys yield high temporal resolution for daily or weekly updates; (2) Easily deployed high resolution surveys in response to reconnaissance results. These two imaging concepts can be implemented by embedding the sources and detectors in and about the storage area with surface-based and borehole based instrumentation. The reconnaissance surveys for leak detection would be implemented, using sparse spatial sampling, to produce high temporal resolution, i.e., daily or weekly, but low-resolution spatial resolution. Circular and cross arrays are proposed as examples of sparse observation systems. If unexpected changes are detected in, existing sources and detectors already embedded can be rapidly and easily activated to produce a high spatial resolution image of the suspected region. Such a monitoring strategy must take advantage of the temporal evolution of the subsurface model and apply temporal regularization and other algorithms to improve the quality of the images generated from sparse datasets. These concepts provide numerous opportunities and challenges in imaging research, e.g., sparse data imaging, methodologies for dynamic imaging, incorporation of flow predictions, and continuous-wave signal processing. Before applying the proposed concepts to the field tests, we must perform numerous simulation studies to test their strength and weaknesses. Some of these simulation results are presented in the following sections.

5.1. Special Acquisition Configurations for Continuous Monitoring

We have described the basic concepts for continuous monitoring in the previous section. Here we explore five special seismic acquisition geometries that have the potential for continuous subsurface monitoring. These proposed observation systems use seismic detectors and low-powered sources permanently embedded in the near surface and in boreholes in order to reduce operation costs and improve repeatability. Simple and composite configurations are made with acquisition units that can be adaptively added and removed during the monitoring phase. We present these special acquisition configurations in this section, and then perform computer simulations in next two sections.

5.1.1. Circular Array

To monitor CO2 injection in a 3-D storage formation, we can use 2-D arrays on the surface to acquire seismic reflection data. With such arrays the reflection data can be processed to produce a 3-D subsurface image. Figure 2(a) shows a circular array surrounding the injection borehole. Overlapped red dots and blue small circles represent sources and receivers, respectively. This simple 2-D array configuration can record reflection seismic data for full 3-D subsurface imaging as shown in Figure 2(b) where reflection points corresponding to this acquisition geometry are displayed. It can be seen that the reflection coverage is very good, and a subsurface image can be obtained within the entire circle, though it will be a low-fold survey. Because the data are continuously acquired, the low-fold spatial coverage can be compensated by the abundant time-lapse data if special imaging algorithms are developed for sparse monitoring data [e.g., 42, 43,44]. We can also use multiple circular arrays to improve the fold and subsequent image quality. Figure 3(a) illustrates a case of two arrays. The total reflection coverage shown in Figure 3(b) results from two independent arrays plus the cross recording between the two arrays. This configuration is flexible and we could add as many circular arrays as we need to reach a trade-off between cost and image quality. In geological CO2 sequestration, the storage volume grows as the injection continues. With this configuration, we can adaptively add more arrays to track the CO2 plume growth.

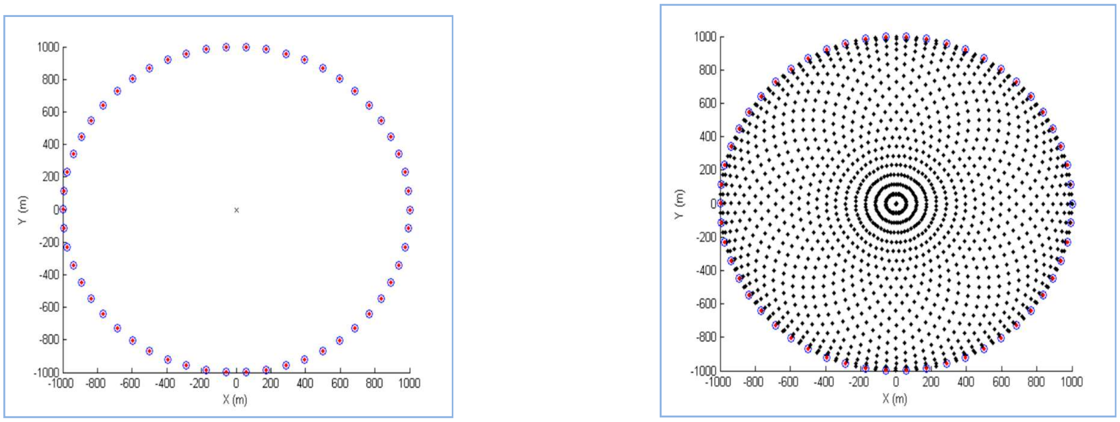


Figure 2: (a) A circular array around an injection borehole; (b) the coverage of reflection points.

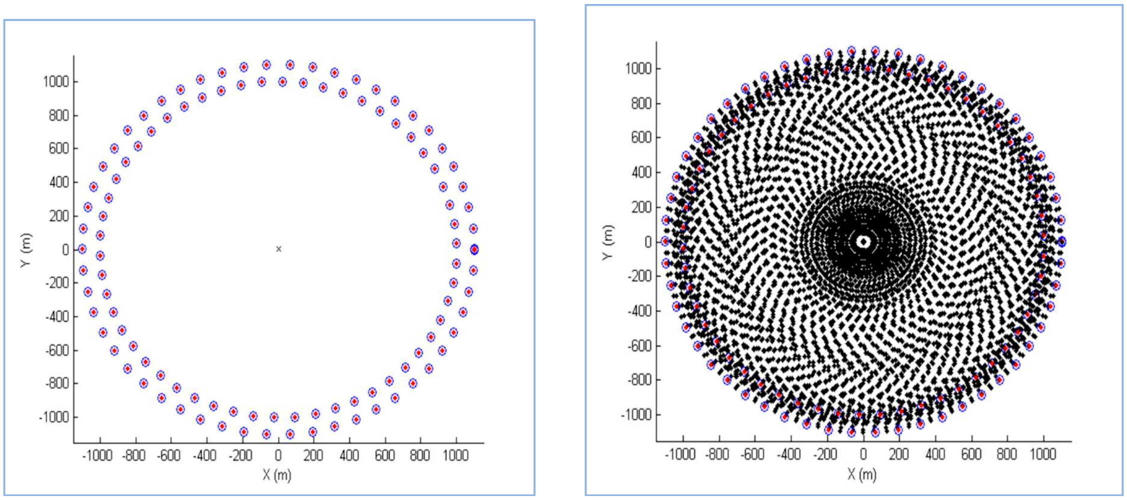


Figure 3: (a) Two circular arrays; (b) the coverage of reflection points, which is the result of two independent arrays plus the cross recording between the two arrays. The fold coverage is significantly improved by an additional array.

5.1.2. Simple Cross Array

A simple cross array (or cross-spread) is shown in Figure 4. The source array (red) and the receiver array (blue) are orthogonal. The shaded area shows the reflection points covered by this acquisition geometry. This simple configuration provides a low-fold true 3-D seismic survey as well, but the coverage is reduced in comparison to the circular array. This sparse 3-D survey does not yield very high resolution, but it may meet the requirements for CO2 sequestration monitoring.

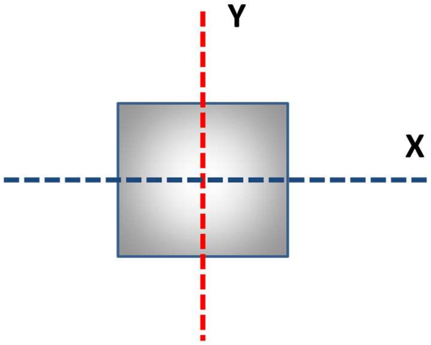


Figure 4: Simple cross array. Red line is a source array; blue line is a receiver array.

5.1.3. 3-D Cross Array

In a CO2 storage project, at least one injection borehole is available. Taking the advantage of using this borehole for monitoring, a vertical detector array may be emplaced in this borehole (Figures 5 and 6). Data recorded in the borehole are Vertical Seismic Profiles (VSP). The combined surface data and the VSP data improve the image quality. VSP data itself can be used to detect the top of CO2 plume with higher accuracy. VSP data also has richer wave-fields, including both up-going and down-going events that provide different views of the targeted zone. Typical VSP data contains high quality S-waves as well as P-waves. Because P-wave and S-wave data have different responses to CO2 saturation and pressure, using both provides a means of distinguishing saturation changes from pressure changes.

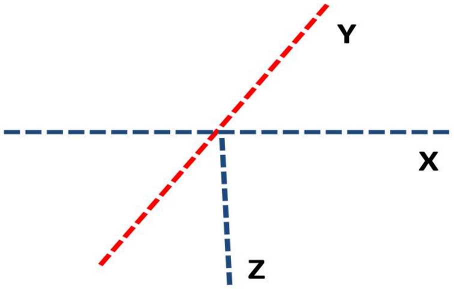


Figure 5: 3-D cross array. A vertical receiver array is added to the surface cross array of sources (red) and detectors (blue).

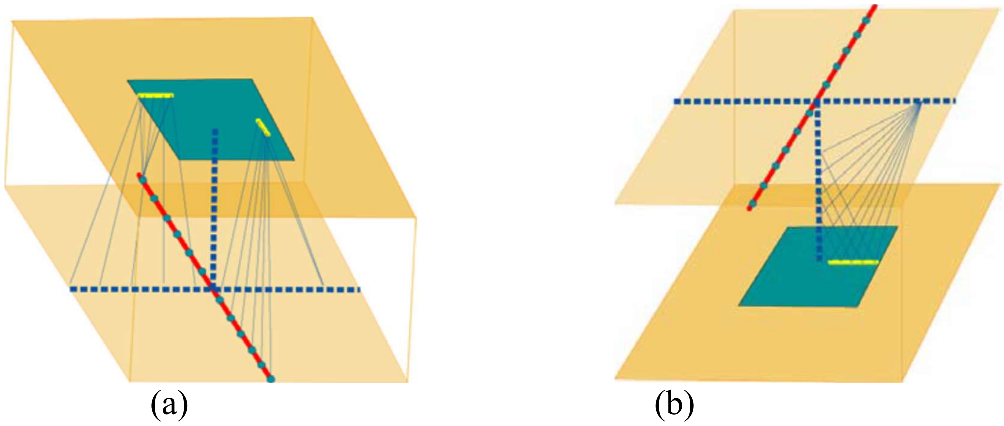


Figure 6: The surface cross array records reflection seismic data (a). The vertical receiver array record both reflection and transmission data (b).

5.1.4. Composite Configurations

We may add more source and receiver arrays and use a composite configuration as shown in Figure 7. Once again, we propose to add a vertical receiver array to several primary surface arrays. With this geometry, high quality 3-D VSP data will be recorded too. The combined datasets provide significant data for high performance time-lapse monitoring.

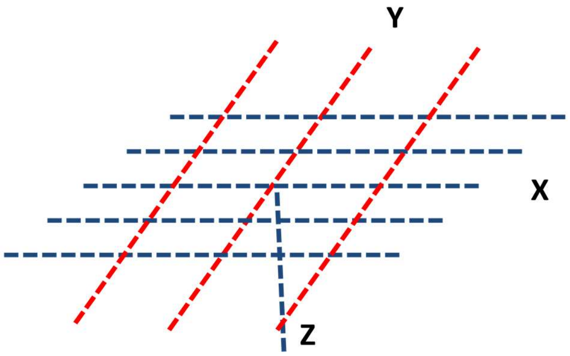


Figure 7: 3-D Composite configuration. In addition to multiple cross arrays, one more source arrays are placed parallel to the receiver arrays.

5.1.5. Adaptive Configurations

The seismic monitoring procedure may last for many years. During this long time period, the CO2 plume may change dynamically, and pathways are not fully predicable.
We should adaptively reconfigure the observation system as illustrated in Figure 8. Simple cross arrays are used as elements in this illustration.

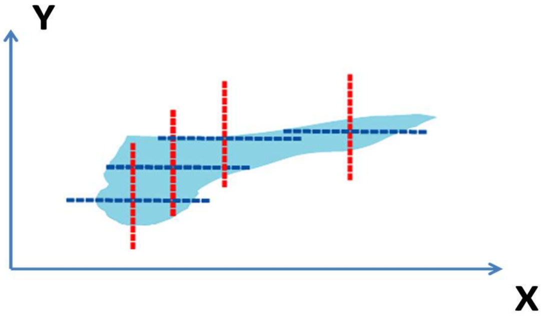


Figure 8: As the CO2 plume grows, the array is moved or more arrays are added to track the plume front.

6. Technological Challenges

The seismic data acquisition challenges presented in the previous chapter lead us to technological challenges to be taken into account in designing a seismic data acquisition system.

The **significant increase of seismic data volume** to be acquired leads to:

1. Data storage aspects on both the field receiver unit and on the central acquisition server;
2. Fast data transmission technologies to be employed;
3. Data compression techniques;
4. Data pre-processing to be performed in the field receiver unit.

The demand for **increased productivity** brings to our attention the following technological challenges:

1. Wireless versus wired;
2. Fast data transmission technologies to be employed (again);
3. Auto-id capability of the field receiver unit: automatic configuration of the receiver line(s);
4. Small power consumption of the field equipment and increased battery duration;
5. Data pre-processing to be performed in the field receiver unit (again);
6. Field equipment ruggedness.

Repeatability:

1. How to determine exact location of the source and of the receivers – GPS;
2. Noise repeatability

Ease of deployment:

Following characteristics were taken into the design:

1. Full wireless; the Land Geophone (WLG) is also wireless, communicating wirelessly with the Wireless Unit (WU)
2. The hardware is designed to be very compact and easy to transport on site
3. The Wireless Land Geophone (WLG) is stored within the Wireless Unit (WU) during transportation (Figure 9).
4. There is no wire connection between any of the elements of the network

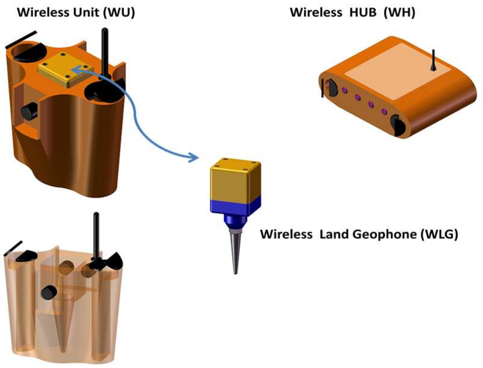


Figure 9: Elements of the Vibrometric Wireless Seismic Array (VWSA). Wireless Land Geophone (WLG) is inserted into the body of the Wireless Unit (WU) for ease of transport and deployment

7. Data Transmission Rate and Data Storage

Before analyzing different data storage possibilities, we should make some calculations of the typical seismic data volume.

Considering the following assumptions:

- Sampling rate (SR = 0.5 / F_{max}): 4,000 samples/sec (¼ ms)
- Analog-to-digital converter (ADC): 24 bits
- WM, daily number of working minutes: 12 h x 60 min
- Daily recording time in seconds (RT): 40 sec/working minute x WM

Then, the daily seismic data volume result for one seismic channel is:

- Volume/channel = ADC x SR x RT = 2,764,800,000 bits / working day = **345.6 MBytes / working day**

For continuous monitoring, the daily volume is much higher:

- Volume/channel = ADC x SR x 3600 x 24 = 8,294,400,000 bits / working day = **1.04 GBytes / day**

From the above, we can also have two other preliminary conclusions:

- To have a real-time data acquisition of this single seismic channel, there is a need of a data transmission rate of: DT_{rate} = ADC x SR x 1.25 (protocol overhead) = **120 Kbps**;
- A seismic field receiver unit would need a data storage capacity of at least: Mem = Daily volume x $N_{channels}$ x N_{days}, where $N_{channels}$ is the number of channels of the seismic field receiver unit (typically one or three channels) and N_{days} is the maximum number of days to store the data on the unit before moving it to a central storage, i.e. memory autonomy. N_{days} should be correlated also with the maximum battery life according to technologies which will be presented later in this document. This is the result if we consider $N_{channels}$ = 3 and N_{days} = 4:
    - Mem = 345.6 Mbytes x 3 x 4 = 4,147.2 Mbytes = **4.147 GBytes**

8. Data Transmission Technologies – Wi-Fi

8.1. Wi-Fi Evolution

Wi-Fi continues to be one of the most widely used wireless technologies in history. More than 1 billion Wi-Fi enabled devices were shipped in 2011, and that number is expected to double by 2015. Many of the new devices in the works are related to consumer media products, health/fitness/medical, automotive, smart meters, and automation products. The figure bellow shows the evolution of Wi-Fi standards, from 1st generation to recently introduced 5th generation:

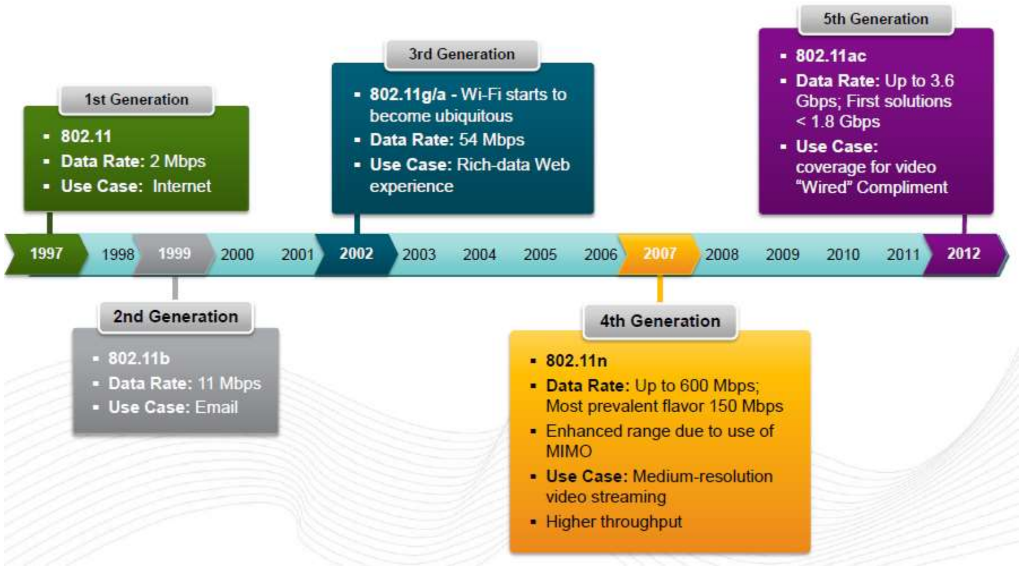


Figure 10: Evolution of Wi-Fi standards

Further on, this document will refer only to Wi-Fi 802.11n and 802.11ac.

8.2. Wi-Fi 802.11n Major Advances

802.11n was a major advance compared with the previous generation with major Medium Access Control (MAC) sublayer and Physical (PHY) layer advances:

- Can be deployed on either the **2.4 GHz or the 5 GHz; 5 GHz** has relatively reduced interference and higher number of non-overlapping channels available compared to 2.4 GHz band.

- Multiple input, multiple output (**MIMO**): It refers to the number of transmit and receive antennas involved in exchanging wireless signals across a propagation channel (2x2 MIMO, for example, indicates two antennas at the transmit end and 2 antennas at the receive end, **the minimum required by the draft 802.11n standard**). Main benefit is:

  - Greater speed without an increase in spectrum consumption using spatial multiplexing (SM). SM splits up the data into pieces and sends each piece along parallel “spatial” channels in a fraction of the time that it would take to send the same data serially. Without SM, 802.11n maxes out at 150 Mbps. With SM, 300 and 450 Mbps are available as long as both transmitter and receiver have at least two and three antennas (and RF chains), respectively.

- **Spatial multiplexing**: MIMO is just one part of the equation. It refers to the number of transmit and receive antennas involved in exchanging wireless signals across a propagation channel

  2x2 MIMO, for example, indicates two antennas at the transmit end and 2 antennas at the receive end, the minimum required by the draft 802.11n standard. 2x3 MIMO indicates two transmitting antennas and 3 receiving antennas. And so forth.

  Spatial multiplexing is a mandatory component of the 802.11n standard, and MIMO is required in order for spatial multiplexing to take place. Thus, the two work hand in hand.

  But what's spatial multiplexing? It's a technique whereby multiple antennas separately send different flows of individually encoded signals (called spatial streams) over the air in parallel; in essence, reusing the wireless medium or "multiplexing" the signals to shove more data through a given channel. At the receiving end, each antenna sees a different mix of the signal streams. In order to decode them accurately, the receiving device needs to separate the signals back out (or "de-multiplex" them).

  The number of spatial streams that can be multiplexed over the air is dependent on the number of transmitting antennas. So while 2x3 MIMO has an additional receive antenna compared to 2x2 MIMO, only two spatial streams can be supported in both configurations.

- **Channel bonding**: By doubling the channel bandwidth from 20 to 40 MHz, a single transmission can carry twice as much data in the same time. Actually, the gain is slightly more than two times since the guard band between the two traditional 20 MHz channels can be used as well.

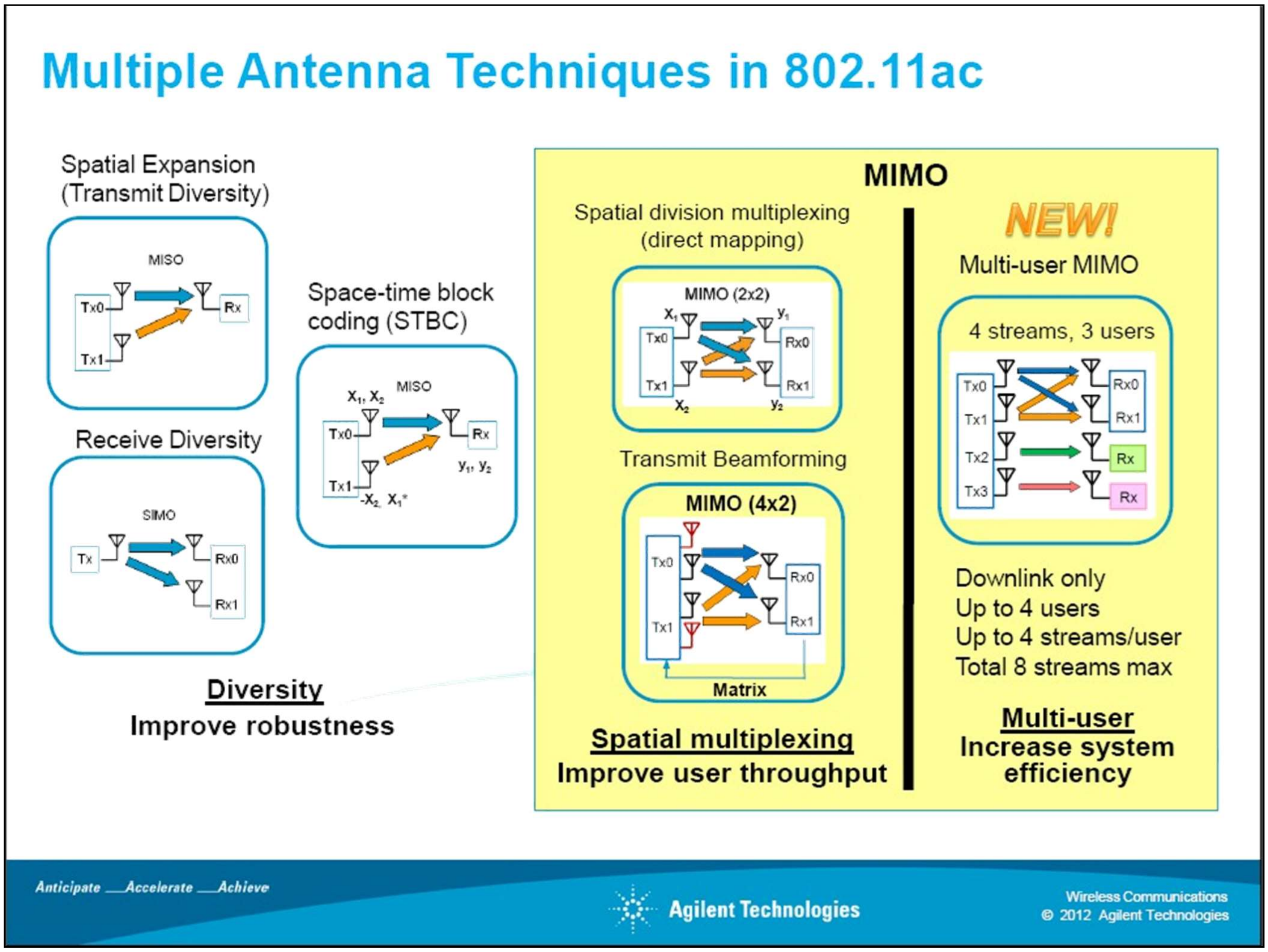
- **MAC aggregation**: Packs small packets in to a larger frame. This reduces the number of frames and hence the time lost to contention for the medium. So, the throughput is increased.

- **Block acknowledgement**: One acknowledgement signal for many frames (as opposed to each frame) and hence making it better for real time applications like video, voice etc.

- **Coverage**: The Access Points that support 802.11n standard covers roughly 1.5 times more distance than the earlier standard (802.11g) per Access Point; (802.11g gave about 30 meters indoor coverage and 100 meters outdoor coverage in the open).

8.3. Wi-Fi 802.11ac Benefits versus 802.11n

- **Channel bonding**: increased from the maximum of 40 MHz in 802.11n, and is now up to 80 or even 160 MHz (for 117% or 333% speed-ups, respectively)
- **Modulation**: higher order 256 QAM Encoding up from 802.11n's 64 QAM (for a 33% speed burst at shorter, yet still usable, ranges)
- **MIMO**: Whereas 802.11n stopped at four spatial streams, 802.11ac goes all the way to eight (for another 100% speed-up).
- **MU-MIMO**



Multiple Antenna Techniques in 802.11ac

Spatial Expansion (Transmit Diversity)

Receive Diversity

Space-time block coding (STBC)

Diversity
Improve robustness

MIMO

Spatial division multiplexing (direct mapping)

Transmit Beamforming

Spatial multiplexing
Improve user throughput

NEW!

Multi-user MIMO

4 streams, 3 users

Downlink only
Up to 4 users
Up to 4 streams/user
Total 8 streams max

Multi-user
Increase system efficiency

Anticipate __Accelerate __Achieve

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Figure 11: Multiple antenna techniques in 802.11ac

- 802.11ac is **5 GHz only technology.**

	Wave 1	**Wave 2**
Standard basis	802.11ac, draft 2.0	802.11ac, final version
Timeframe	Mid-2013	2014
Channel width	20, 40, and 80 MHz	Potential to add 160 MHz channels
Modulation support	Up to 256-QAM	Same as wave 1
Lowest 11ac speed	173 Mbps (20 MHz, 2-stream, 256-QAM)	Same as wave 1
Typical 11ac speed	867 Mbps (80 MHz, 3-stream, 256-QAM)	1.7 Gbps (160 MHz, 3-stream, 256-QAM)
Maximum 11ac speed	1.3 Gbps (80 MHz, 3-stream, 256-QAM)	3.5 Gbps (160 MHz, 4-stream, 256-QAM)
Beamforming	Yes (depending on underlying chipset)	Yes, possibly MU-MIMO

Table 1: 802.11ac technology waves

We will further refer only to Wave 1 technological limits.

8.4. Theoretical Throughput

(From IEEE_802.11ac)

Theoretical throughput for single Spatial Stream (in Mb/s)

MCS index	**Modulation type**	**Coding rate**	**20 MHz**		**40 MHz**		**80 MHz channels**		**160 MHz**	
			800 ns	**400 ns**	**800 ns**	**400 ns**	**800 ns**	**400 ns**	**800 ns**	**400 ns**
0	BPSK	½	6.5	7.2	13.5	15	29.3	32.5	58.5	65
1	QPSK	½	13	14.4	27	30	58.5	65	117	130
2	QPSK	¾	19.5	21.7	40.5	45	87.8	97.5	175.5	195
3	16-QAM	½	26	28.9	54	60	117	130	234	260
4	16-QAM	¾	39	43.3	81	90	175.5	195	351	390
5	**64-QAM**	**2/3**	**52**	**57.8**	**108**	**120**	**234**	**260**	**468**	**520**

6	**64-QAM**	¾	**58.5**	**65**	**121.5**	**135**	**263.3**	**292.5**	**526.5**	**585**
7	**64-QAM**	**5/6**	**65**	**72.2**	**135**	**150**	**292.5**	**325**	**585**	**650**
8	**256-QAM**	¾	**78**	**86.7**	**162**	**180**	**351**	**390**	**702**	**780**
9	**256-QAM**	**5/6**	**N/A**	**N/A**	**180**	**200**	**390**	**433.3**	**780**	**866.7**

Table 2: Theoretical throughput for single Spatial Stream (in Mb/s)

8.5. Available Radio Channels

2.4 GHz Band

Most people are familiar with 2.4GHz band for Wi-Fi operation which provides 3 non-overlapping channels of 20MHz resulting in total channel capacity of 60MHz. Most interference in this band comes from microwave, Bluetooth and digital phones, which administrators are familiar with, are usually temporary in nature, and can be mitigated by appropriately moving the interfering device.

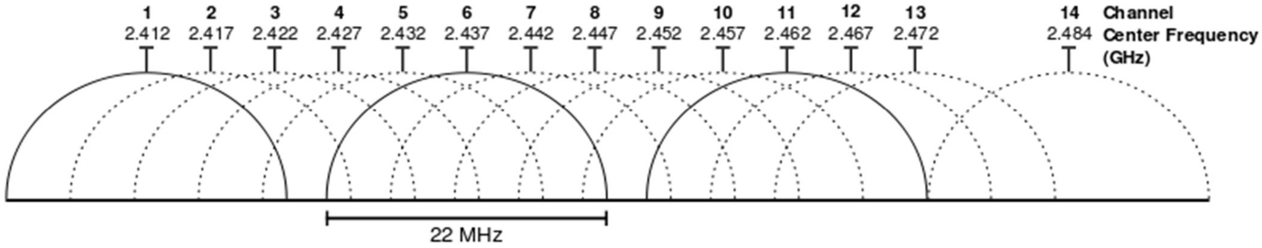


Figure 12: 2.4 GHz Band available radio channels

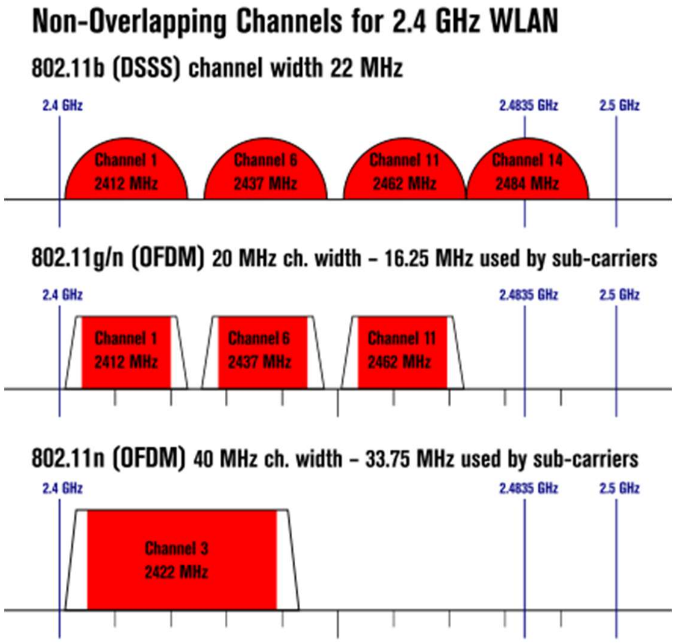


Figure 13: 2.4 GHz Non-overlapping channels

The figure above shows that only 3 of the 13 channels are completely non-interfering or so called orthogonal.

5 GHz Band

New Wi-Fi technologies like 802.11n and 802.11ac also uses 5 GHz band. In fact, the latest Wi-Fi standard, 802.11ac only operates in the 5GHz band with wave 1 radio chipsets capable of bonding 4 20MHz channels providing a channel width of up to 80MH for a single transmission with data rates of 1.3 Gbps. The wave 2 chipsets will be able to bond 8 20MHz channel for a total channel width of 160MHz for single transmission rate of 3.5 Gbps.

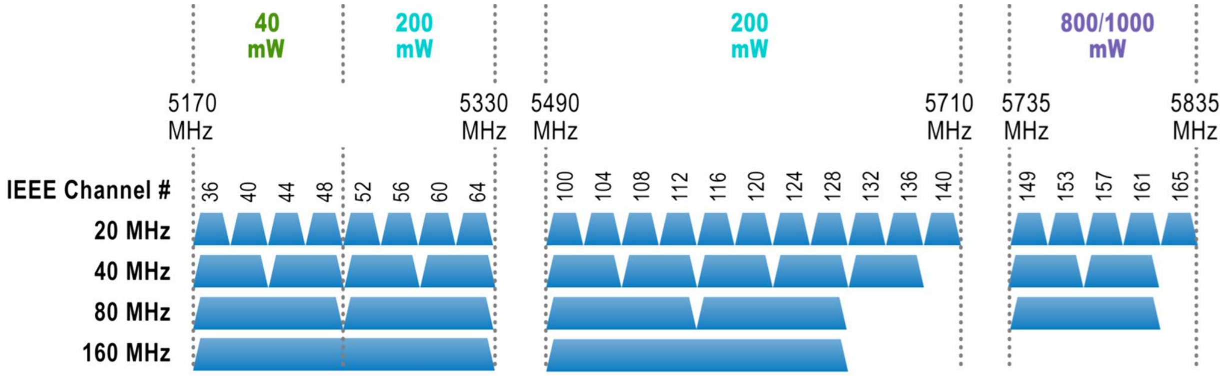


Figure 14: US channel allocations for 20/40/80/160 MHz in 5 GHz

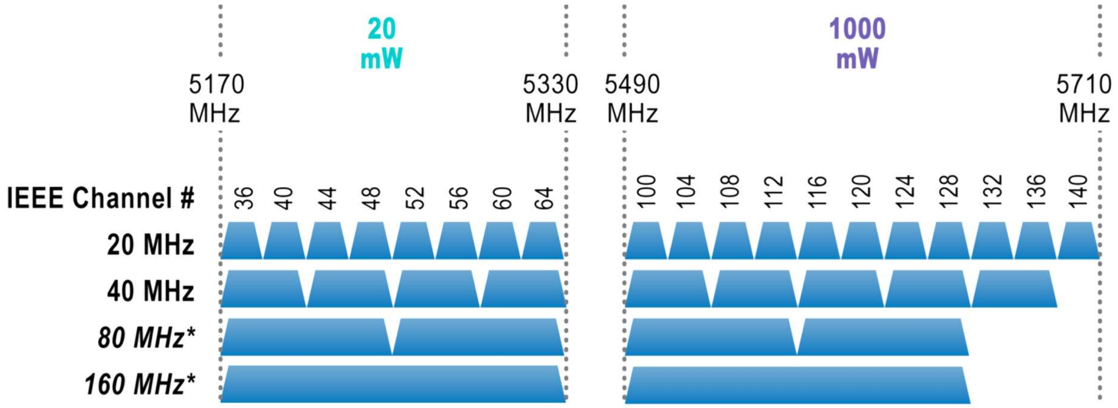


Figure 15: European channel allocations for 20/40/80/160 MHz in 5 GHz

It is important to understand the regulatory aspects for the 5GHz band. **Many of the frequencies in the 5GHz band are also used by radar equipment for first responders**, **airports, weather stations and military installations.** Because of this there are very stringent government regulatory requirements that must be followed by Wi-Fi radios when operating on these frequencies. The regulatory bodies specifying and enforcing these requirements in North America is the Federal Communications Commission (FCC) and in the European Union it is the European Telecommunications Standards Institutes (ETSI). Requirements/specifications for operating on the 5GHz band are called **Dynamic Frequency Selection (DFS).** DFS allows unlicensed devices to use the 5GHz band already allocated to radar systems without causing interference to those systems.

CHANNEL NUMBER	FREQUENCY MHZ	EUROPE (ETSI)	NORTH AMERICA (FCC)	JAPAN
36	5180	Indoors	✓	✓
40	5200	Indoors	✓	✓
44	5220	Indoors	✓	✓
48	5240	Indoors	✓	✓
52	5260	Indoors / DFS / TPC	DFS	DFS / TPC
56	5280	Indoors / DFS / TPC	DFS	DFS / TPC
60	5300	Indoors / DFS / TPC	DFS	DFS / TPC
64	5320	Indoors / DFS / TPC	DFS	DFS / TPC
100	5500	DFS / TPC	DFS	DFS / TPC
104	5520	DFS / TPC	DFS	DFS / TPC
108	5540	DFS / TPC	DFS	DFS / TPC
112	5560	DFS / TPC	DFS	DFS / TPC
116	5580	DFS / TPC	DFS	DFS / TPC
120	5600	DFS / TPC	No Access	DFS / TPC
124	5620	DFS / TPC	No Access	DFS / TPC
128	5640	DFS / TPC	No Access	DFS / TPC
132	5660	DFS / TPC	DFS	DFS / TPC
136	5680	DFS / TPC	DFS	DFS / TPC
140	5700	DFS / TPC	DFS	DFS / TPC
149	5745	SRD	✓	No Access
153	5765	SRD	✓	No Access
157	5785	SRD	✓	No Access
161	5805	SRD	✓	No Access
165	5825	SRD	✓	No Access

Table 3: 5 GHz channels

These DFS requirements are complex and costly to get regulatory certification from FCC/ETSI. Following are the typical requirements for access points (AP) operating on 5GHz DFS channel:

1. Before starting operation on DFS channel, scan the channel for Radar devices for 1 minute. If radar is detected follow step 4 otherwise start operation of DFS channel.
2. Must detect non-Wi-Fi Radar devices with pulse width as small as 5us
3. When radar device are detected stop operation on the channel within 500 milliseconds.
4. For AP vendors, this also means informing wireless clients to move away from this channel.
5. Do not become operational of this DFS channel for at least 30 minutes and after that go to step 1 before becoming operational again.

Given the above complexity many small office-home office vendors as well as some enterprise AP vendors don't allow operation on DFS channels in the 5 GHz band at all. Many client devices are also not certified for DFS band operation. Even when Aps are certified and support DFS channels AP vendors often recommend operation exclusively on non-DFS channels given the uncertainty of DFS channels support at the client device level.

Given above complexities of operating on DFS channel, it is prudent to look at how many DFS and non-DFS channels are available in 5GHz band. Table below provides that break down.

	UNII-1 (5150-5250)				UNII-2 (5250-5350)				Intermediate (5450-5725)											UNII-3 (5725-5825)			
Channel	36	40	44	48	52	56	60	64	100	104	108	112	116	120	124	128	132	136	140	149	153	157	161
FCC (Americas)	√	√	√	√	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	√	√	√	√
ETSI (EMEA)	√	√	√	√	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D				
KCC (Korea)	√	√	√	√																D	D	D	D
MIC (Japan)	√	√	√	√	D	D	D	D															

Table 4: Break down of DFS and non-DFS channels

8.6. Wi-Fi Direct

Wi-Fi Direct is not the same as ad-hoc networking: The most significant difference between traditional ad-hoc wireless networking (traditional peer-to-peer networking) and Wi-Fi Direct is security. In Windows ad-hoc networks, the highest level of security supported is WEP in mixed client environments (Windows 7 will support WPA2 provided all adapters support it, as well). Wi-Fi Direct, as mentioned, supports WPA2. Another difference, Wi-Fi Direct devices can also simultaneously connect to existing wireless networks. More granular control and better discovery of devices also differentiate Wi-Fi Direct from ad-hoc networking.

Wi-Fi Direct is an emerging technology meant to meet the growing demand for easy, portable wireless network connectivity. It's peer-to-peer wireless networking, which means that wireless devices such as notebooks, Mobile phones, PC, printers etc. can "find" one another and establish wireless connectivity without need of the presence of a wireless router, an access point, or Wi-Fi hotspots.

Wireless devices can now connect to each other directly to transfer content and share applications quickly and easily. Devices can make a one-to-one connection, or a group of several devices can connect simultaneously.

Connections based on the specification will work at typical Wi-Fi speeds and range, protected by WPA2. So the most significant difference between traditional ad-hoc wireless networking (traditional peer-to-peer networking) and Wi-Fi Direct is security, speed and range.

The Wi-Fi direct supports concurrent hosting and client capabilities on single interface.

Vibrometric will base its design for the Wireless Seismic Array on WiFi Direct standard and 5GHz band for the transmission standard from WU's and 2GHz band for the transmission between Wireless Hub's (WH).

9. Draft Design of Vibrometric Wireless Unit (WU) Seismic Array (WUSA)

9.1. Technical Characteristics

There are some important considerations regarding desired performance and technical characteristics which will be listed bellow and will be taken into account in our draft design:

Parameter	**Desired value**	**Typical value currently on the market**
Sampling rate	4000 samples/second	500 (1000) samples/second
Number of seismic channels	Hundreds / Thousands	Hundreds / Thousands
Analog-to-digital converter (ADC) bits	24	24
Wireless data transmission	Yes – based on latest 802.11ac technology (open standard)	Yes (proprietary)
Number of geophones for each wireless unit	1 or 3	1 or 3
Geophones with wireless (Bluetooth) transmission to wireless unit	Yes	No (they connect with wires)
Wireless unit flash memory	32/64 GB	16/32 GB
Wireless unit battery life	Days	Days
Wireless unit solar panel	Yes	No
Wireless unit GPS	Yes	Yes
Wireless unit Near field communication (NFC)	Yes	No - only radio-frequency identification (RFID) available
Array self-configuration	Yes	Rare
Array self-diagnostic	Yes	Rare

Seismic data compression	Possible	No
Seismic data stacking on the wireless unit	Yes	No
Real-time seismic data transmission	Yes – for thousands of channels	Yes – for hundreds of channels / No (data harvesting after data acquisition)

Table 5: Wireless Unit (WU) technical characteristics

9.2. Required Data Throughput for Wireless Unit

In the bellow table is determined the necessary throughput for a WU:

Sample rate, samples/second	4,000
ADC bits	24
Geophones per Wi-Fi unit	3
Protocol overhead(1)	1.25
Number of bits covering 1 second of seismic data	360,000
Throughput, Mbps / Wireless unit (= sample rate x ADC x no. geophones x protocol overhead / 1000 /1000)	**0.360**

(1) – The protocol overhead (25%) is needed for data packets ID, data integrity check (Cyclic Redundancy Check – CRC), etc. The 1.25 factor is a good assumption which in fact should be reduced in the design phase.

Table 6: Required Data Throughput for WU

9.3. Typical 3D seismic layout

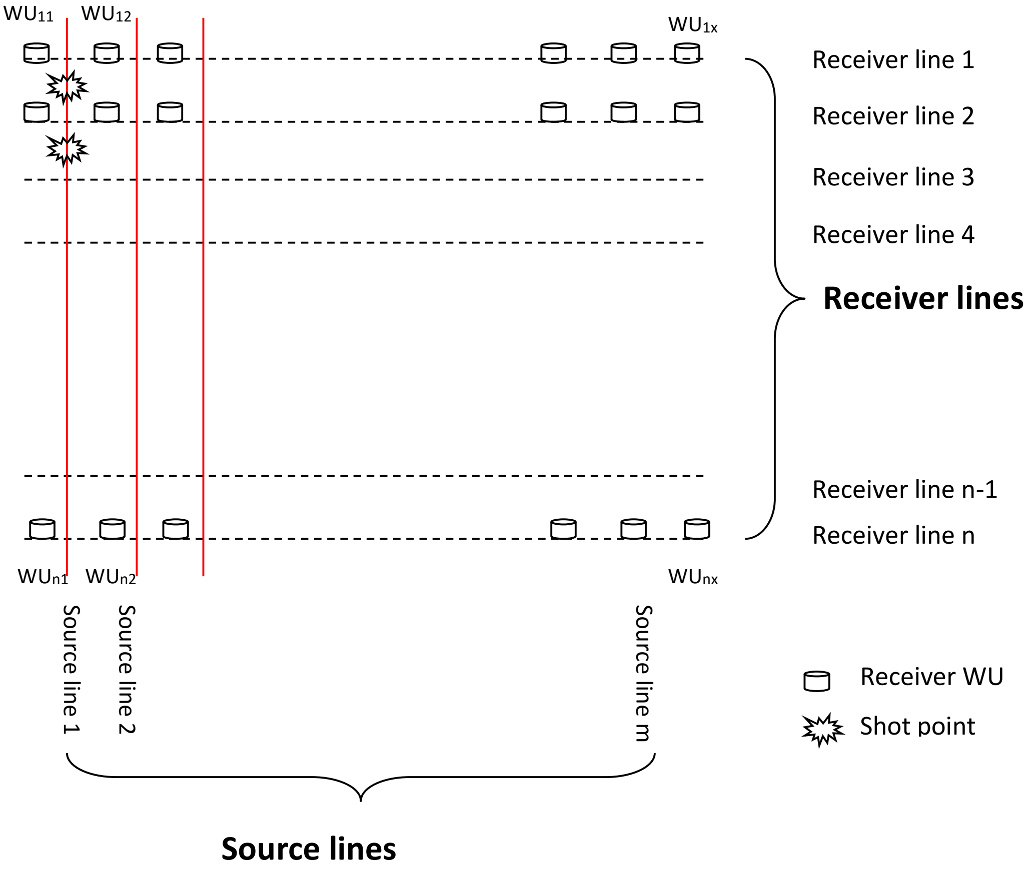


Figure 16: Typical 3D seismic layout

The figure above presents a typical 3D seismic layout:

- n receiver lines
- m source lines
- x receiver wireless units on each line

9.4. Theoretical number of WUs in a seismic line and possible layouts

We define as near real time seismic data transmission: x seconds from the end of the acquisition time, all aggregate data arrives at a central processing point. We want to achieve a value which is less or equal than source movement time from current shot point to the next one; normally x <= 5 seconds.

We analyze the case when the seismic data will be transmitted sequentially from one WU to another through Wi-Fi Direct. The seismic line consists of WU$_1$ to WU$_n$:

- from WU$_1$ data is send to WU$_2$;
- WU$_2$ will act as a relay but will add its own data and will transmit WU$_1$ + WU$_2$ data to WU$_3$;
- WU$_3$ will act as a relay but will add its own data and will transmit WU$_1$ + WU$_2$ + WU$_3$ data to WU$_4$ and so on… (see the figure bellow);
- WU$_n$ will have all the seismic line data.

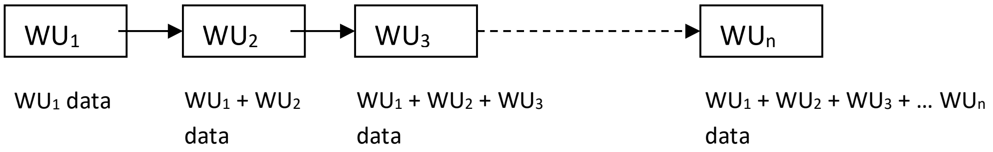


Figure 17: Seismic line – layout 1 with a single frequency

WU1	t1									
WU2		t2	t1							
WU3				t3	t2	t1				
WU4							t4	t3	t2	t1

…

Figure 18: Seismic line – time slots used in layout 1

From the figure above:

- t1, t2, ….tn represents transmission time (slot time) for one second of seismic data from one unit; in fact t1 = t2 = t3 = … = tn = T_u
- The total transmission time for n WU is $T_{total} = T_u \times n \times (n + 1) / 2$.

The slot time is equal with “bit transmission time” multiplied by “number of bits covering 1 second of seismic data”: T_u = 0.00000617 msec x 360,000 bits = 2.22 msec.

Thus, if we want to have 250 WUs on a seismic line (n = 250), T_{total} = 2.22 x 250 x 251/2 = 69.72 sec.

This is over a minute and it cannot be considered near real time, is well over the 5 seconds limit (see the above consideration regarding the near real time transmission).

As WiFi Direct allows units to be both Host and Client, in order to achieve a near real time transmission, we chose the methodology of below, by which 3 units will transmit near-simultaneously on one frequency (channel) through a complex transmission algorithm with non-collision avoidance and self-configuration capability.

Possible layout of a seismic line with 3 orthogonal radio channels used simultaneously (f1, f2, and f3):

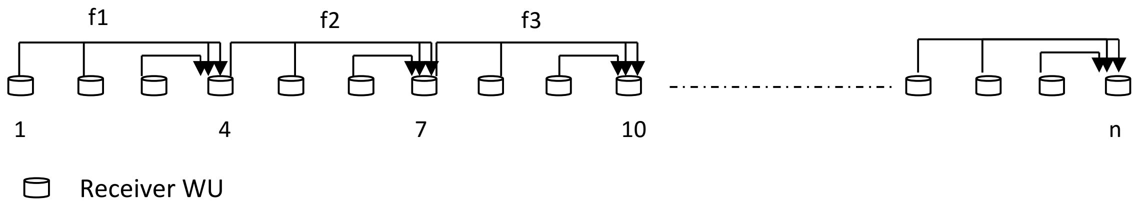


Figure 19: Seismic line – layout 2 with a three frequencies

These are technical aspects of the above layout:

- WU 1, 2, 3 transmit the seismic data to WU4 on channel f1; WU4, 5, 6 transmit the seismic data to WU7 on channel f2; WU7, 8, 9 transmit the seismic data to WU10 on channel f3; using orthogonal channels, we avoid radio interference.
- These 3-to-1 (many-to-one) transmissions occur simultaneously along the seismic line; the radio channels are reused, e.g. 1-4 on f1, 4-7 on f2, 7-10 on f3, 10-13 on f1, 13-16 on f2, 16-19 on f3, and so on. It is based on the many-to-one capability of Wi-Fi Direct.
- Stations 4, 7, 10,…, operate simultaneously on two frequencies (4 on f1 and f2, 7 on f2 and f3, 10 on f3 and f1, …) having two concurrent Wi-Fi sessions: AP for the previous 3 units and client for the next AP (Wi-Fi direct supports concurrent hosting and client capabilities on single interface)

In the table below, the transmission principle is presented for the first 12 WU's as to prove that our calculations for the total time required for the transmission of 1 second of acquired data is correct.

Regarding the protocol and the algorithm, please refer also to the following sub-chapter, 8.6 Network configuration.

Number of time slots used in this layout

wu1	wu2	wu3	wu4	wu5	wu6	wu7	wu8	wu9	wu10	wu11	wu12
t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	**t11**	
1(1)4	2(2)4	3(3)4	4(1)7	4(2)7	4(3)7	4(4)7					
5(5)7	6(6)7	7(5)10	7(6)10	7(7)10	7(1)10	7(2)10	7(3)10	7(4)10			
8(8)10	9(9)10	10(8)12	10(9)12	10(5)12	10(6)12	10(7)12	10(1)12	10(2)12	10(3)12	10(4)12	
11(11)12	10(10)12										
4:1,4	4:1,2,4	4:1,2,3,4	4:1,2,3,4	4:1,2,3,4	4:1,2,3,4	4:1,2,3,4	4:1,2,3,4	4:1,2,3,4	4:1,2,3,4		
7:5,7	7:5,6,7	7:5,6,7	7:1,5,6,7	7:1,2,5,6,7	7:1,2,3,5,6,7	7:1,2,3,4,5,6,7	7:1,2,3,4,5,6,7	7:1,2,3,4,5,6,7	7:1,2,3,4,5,6,7		
10:8,10	10:8,9,10	10:5,8,9,10	10:5,6,8,9,10	10:5,6,7,8,9,10	10:1,5,6,7,8,9,10	10:1,2,5,6,7,8,9,10	10:1,2,3,5,6,7,8,9,10	10:1,2,3,4,5,6,7,8,9,10	10:1,2,3,4,5,6,7,8,9,10		
12:11,12	12:10,11,12	12:8,10,11,12	12:8,9,10,11,12	12:5,8,9,10,11,12	12:5,6,8,9,10,11,12	12:5,6,7,8,9,10,11,12	12:1,5,6,7,8,9,10,11,12	12:1,2,5,6,7,8,9,10,11,12	12:1,2,3,5,6,7,8,9,10,11,12	12:1,2,3,4,5,6,7,8,9,10,11,12	

Number of time slots = n – 1, where n is the number of WUs on the seismic line.

Thus, if we want to have 250 WUs on a seismic line (n = 250), T_{total} = 2.22 x 249 = 0.55 sec. If the seismic line is arranged as below, data from 500 WUs can be transmitted in the above time (1 second of acquisition). The assumption is for 3 Wireless Land Geophone (WLG) per Wireless Unit (WU), so 3 channels for one WU. They system designed at this stage in terms of the Hardware presented is for 1 WLG/WU.

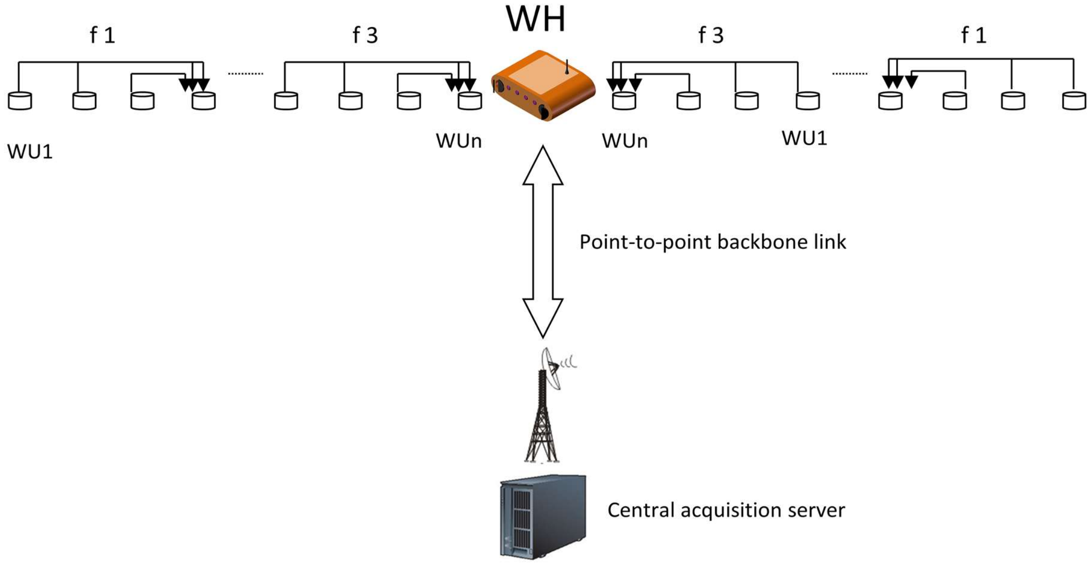


Figure 20: Seismic line – layout 2 with three frequencies and 2 segments

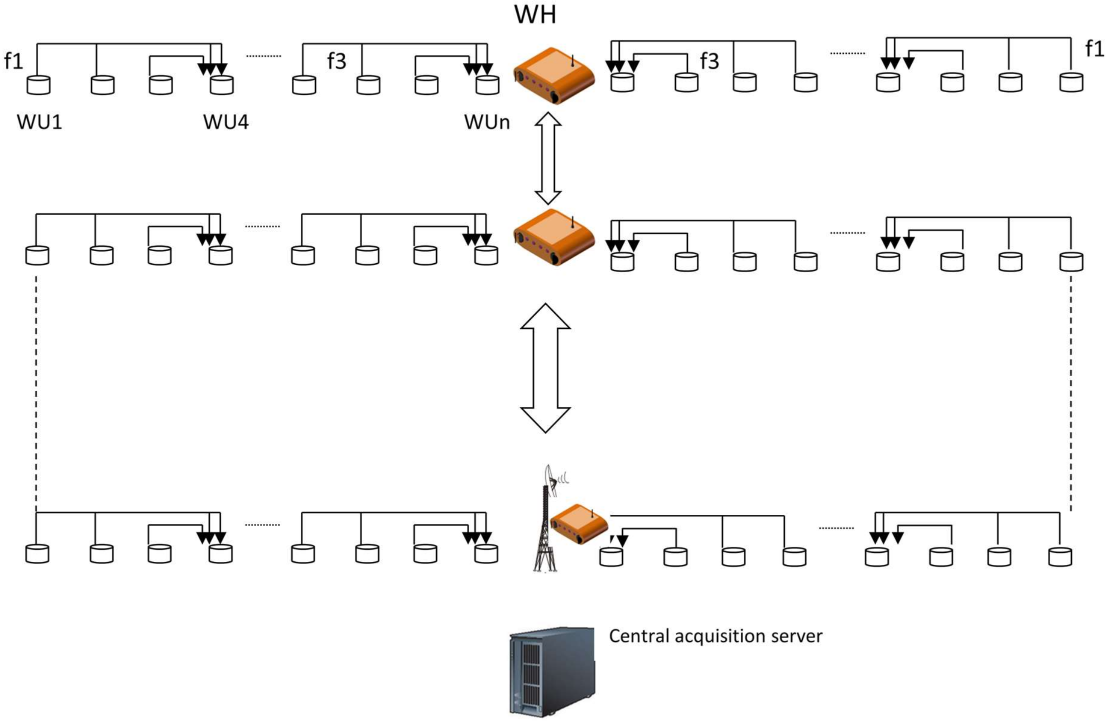


Figure 21: Seismic 3D grid – layout 3

In each WU would be in fact **two parallel processes** running during the seismic data acquisition, called a sweep that typically lasts 15 to 30 seconds:

- PROCESS 1: The data acquisition including the ADC conversion;
- PROCESS 2: The data transmission to the next unit

Thus, WU acquires and digitizes 1 second (time frame) of seismic data and in the beginning of the next 1 second time frame, in parallel with data acquisition and digitizing, will transmit its own data/data of 3 previous WU's.

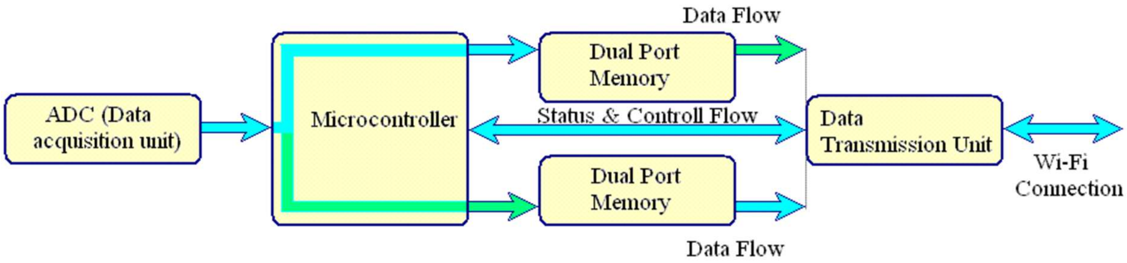


Figure 22: WU processes

	Theoretical throughput for single Spatial Stream (in Mb/s)
256 QAM 802.11ac, **20 Hz** ch., coding rate ¾	78
256 QAM 802.11ac, **40 Hz** ch., coding rate ¾	162
256 QAM 802.11ac, **80 Hz** ch., coding rate ¾	351
2x2 MIMO spatial stream multiplexing, **20 Hz** ch.	156
2x2 MIMO spatial stream multiplexing, **40 Hz** ch.	324
2x2 MIMO spatial stream multiplexing, **80 Hz** ch.	702

Table 7: Theoretical data throughput

In the highlighted row of the above table: Wi-Fi 802.11ac will be used, with 40 Hz channel (5 GHz band), and with 1 spatial stream.

9.5. Number of WUs in a 3D seismic layout and theoretical number of channels to be covered by the system

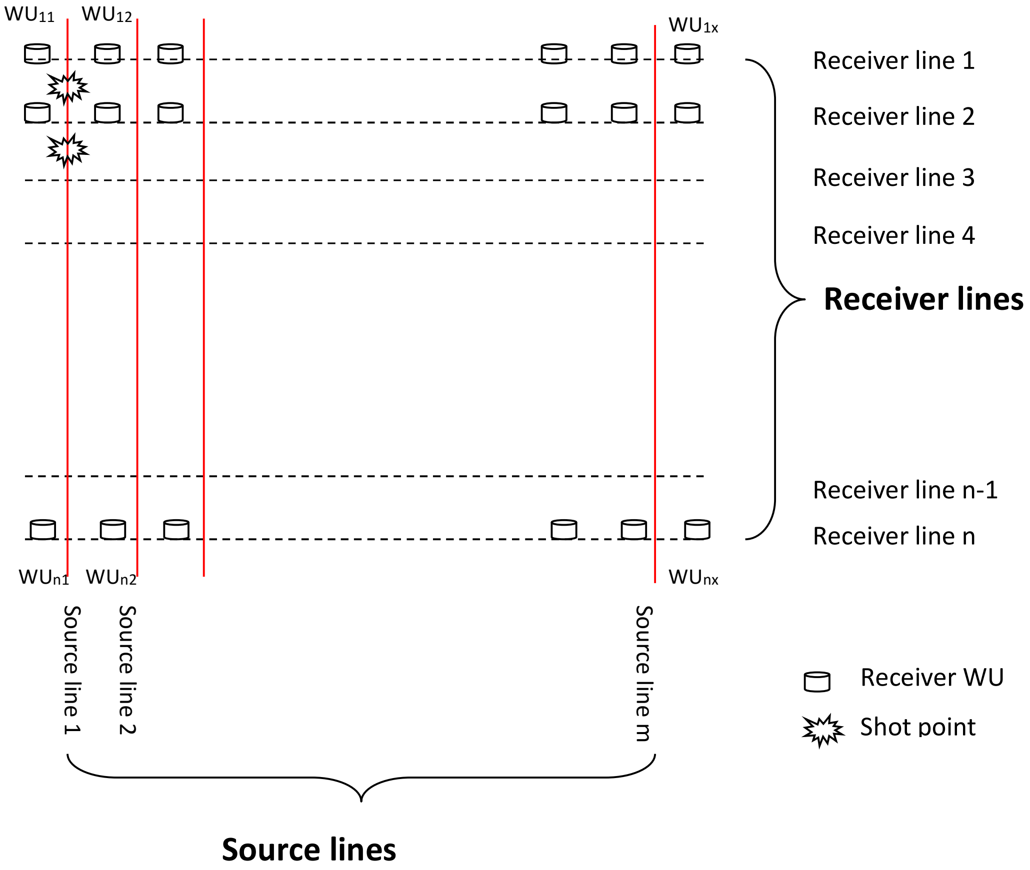


Figure 23: 3D seismic layout

Based on the above assumptions, if the number of WU units on a line can be up to 500 WUs with 3 channels for a near-real time transmission, the total number of channels in a grid of 5 lines that can be deployed in order to have near real time seismic data acquisition at a sampling rate of ¼ ms (4,000 samples/sec) will closely be 7,500.

9.6. Network self-configuration

As shown above, in a network that will include hundreds of WU's, is necessary that the data transmission among them and toward the Central Acquisition Center to be done on a multiple of channels *simultaneously.* The chosen open standard for transmission is WiFi direct, 5 GHz band. The number of usable channels without conflicting with radar systems is 4, so we need to use them (in the simultaneous mode that is necessary) in an intelligent configuration in order to avoid collisions (overlapping).

Following this assumption, at any moment of time, every element (WU) should have set certain frequency/channel on which will transmit its own data (and the data of previous WU's) toward the neighbor WU. This can be done in two ways:

a) establishing fixed frequencies for each element at fixed times of transmission. This solution is not advantageous in our case due to the following aspects:
    - it implies a complex plan of setting, especially in the case of large networks
    - the WU elements remain fixed, with no possibility to have other position in the network without reprogramming that unit
    - it implies different types of units, used in the network according to the setting plan
    - it implies a large number of spare units
    - installation is laborious and can easily lead to wrong place assignment
b) building a network of WU elements capable of self-configuration, i.e. each WU element is capable to choose freely the communication channels (frequencies) with the neighbor WU element, so that the rate of possibility for channel collision is drastically diminished
c) by combining the technique in b) with that of the ability of each WU element self-decide the exact time to do the transmission of the data

The communication protocol that will be used is described as follow: we define bi-dimensionally the space having on one axe the channel auto-location (space sharing) and on the other the time (time sharing), as presented in fig. 23.

Time sharing implies the choice of a base time unit (e.g. 1 second for the sake of ease of explanation) and the conventional division in a distinct number of time slots. In fig. 23, for the sake of ease of explanation, we chose a division into 16 time slots. The time slot should be as near as possible to the time unit calculated above (that can be different depending on the local conditions) for one WU to send 1 second of acquired data. The self-configuration algorithm will involve an initialization step, during which a routine will be run for a) numbering the units, b) finding the most efficient duration for the time slot to be used, c) finding the number of channels available (using DFS, the radar channels will be detected and the number of available channels will be determined - f1, f2, f3.... in the fig.23) and d) allocating to the units the right frequency and time slot for the transmission.. A session of communication between 2 elements cannot take place but only during a specific time-slot. No other element will be permitted to initiate another communication session during that specific time slot.

Legend: WU1: Wireless Unit 1 transmits its own data. Same for WU2, WU3 etc…
WU4 (WU1): Wireless Unit 4 transmit data of Wireless Unit 1. Same for
WU4 (WU2), WU4 (WU3) etc……

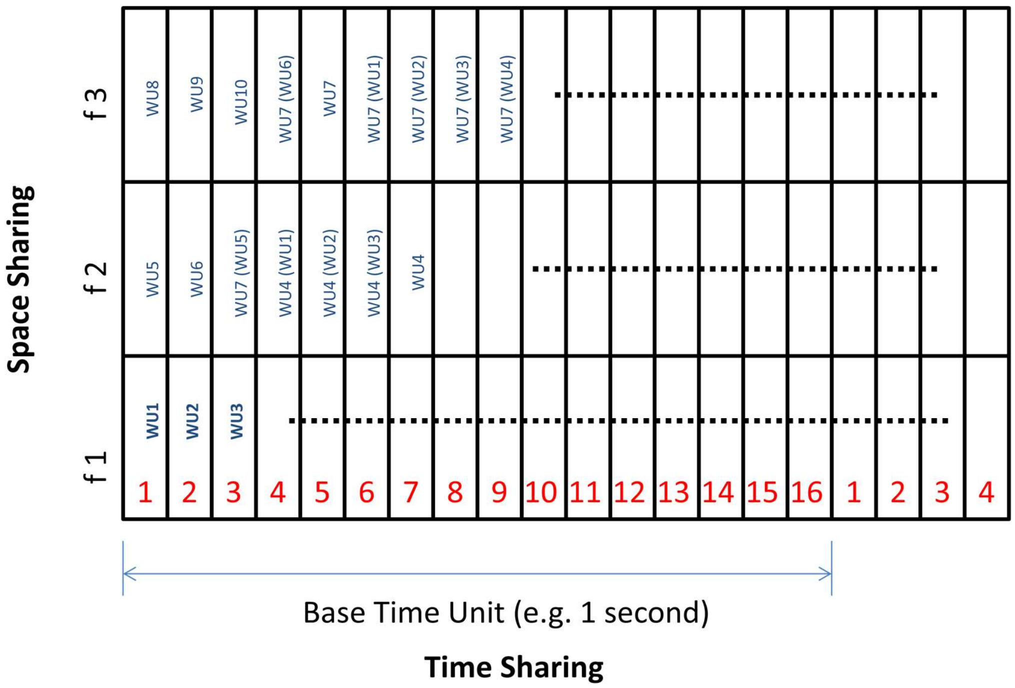


Figure 24: Space/Time sharing

In the field, as mentioned above, after the positioning of the elements in their acquisition position, will follow an auto-configuration session of the network. The Central Server will broadcast a routine (messages) to all units in the network. As they receive this signal, each element will define and will be allocated one time slot and one frequency to operate during on-line session of acquired data transmission. During the initialization routine, this is done until no collisions will appear, then they are fixed for each element.

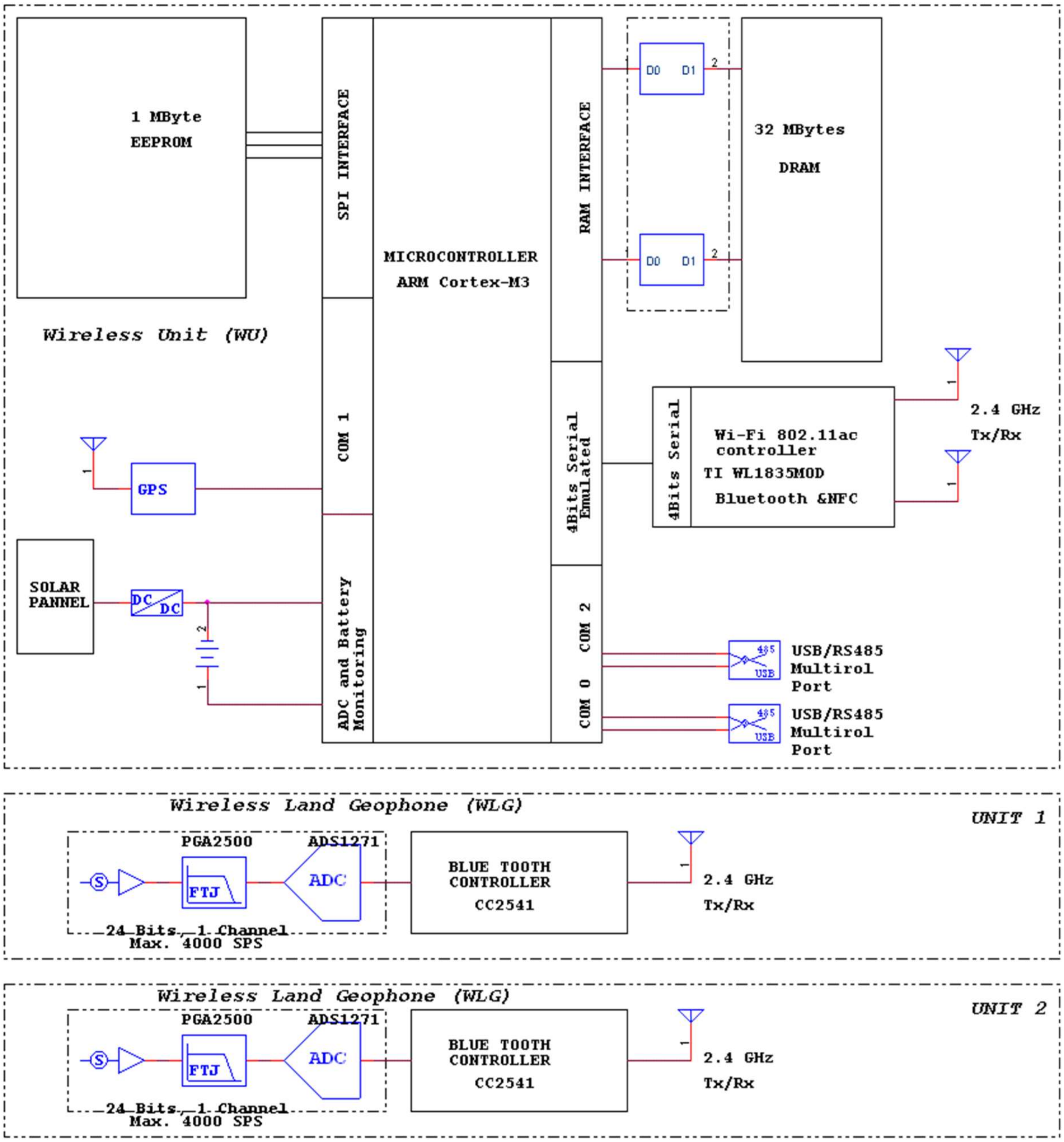
After this initialization session which duration will depend on the network size, each element will be configured, i.e. will be set with a frequency and a time slot for transmission.

During the operating mode, it is normal to keep the synchronization of the network elements, so a superposition in transmission between the adjacent elements is avoided. In this desiderate, the WU's will use the transmission signal of the adjacent unit also as synchronization signal. Thus, the allocated time slot duration will need to include also this time for synchronization (part of the overhead included in the time unit calculation in the previous chapters), so to avoid gaps in the synchronization.

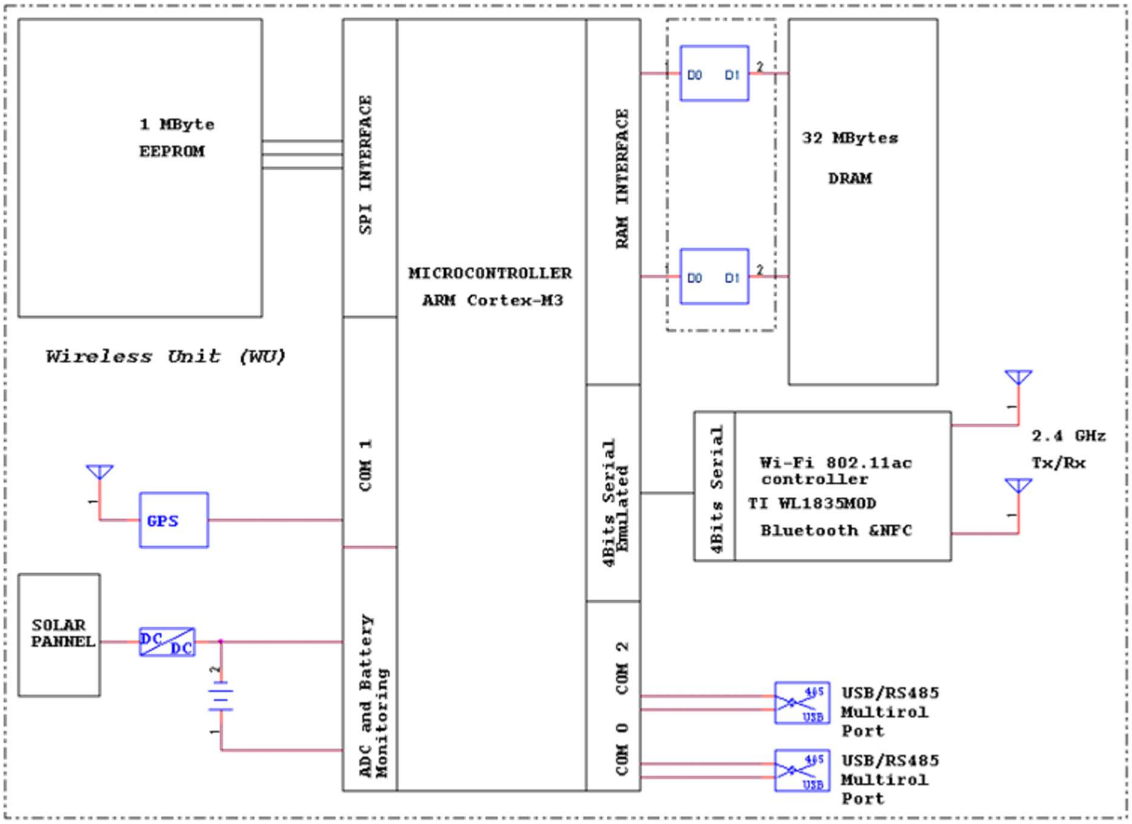
The transmission between the wireless hubs (WH) until the last WH we use the same technique. To avoid interference with the WU's, we will use the WiFi in 2 GHz band. For the link between the network (last WH in the network) and the Central Server, a high capacity radio link will be used. The Vibrometric choice is for:

10. Hardware

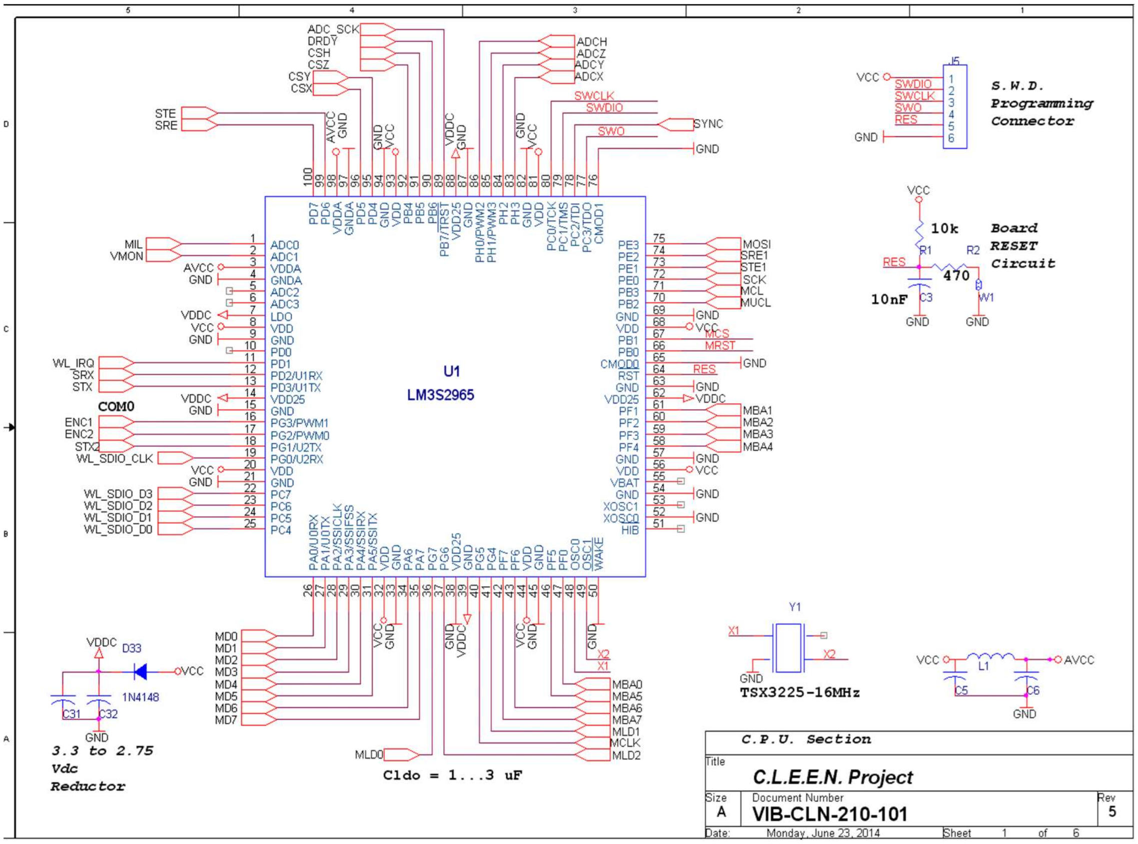
10.1. Block Diagram



10.2. WU Block Diagram

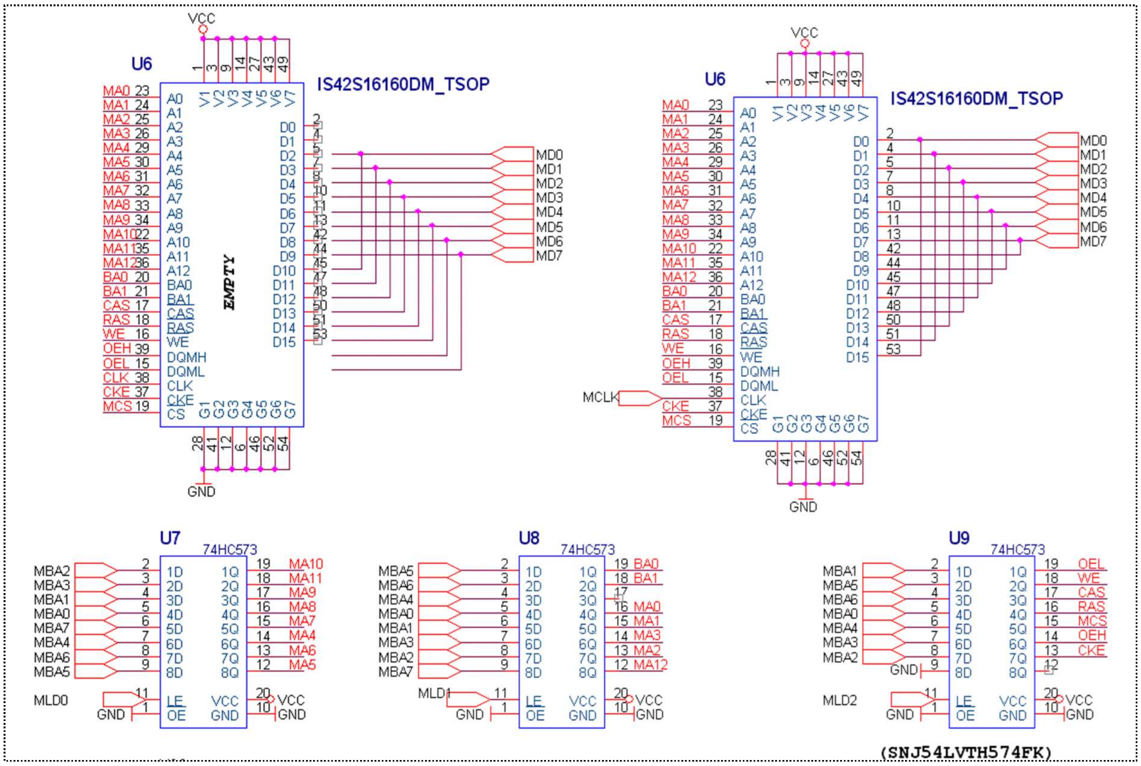


The unit main blocks are shortly presented below.



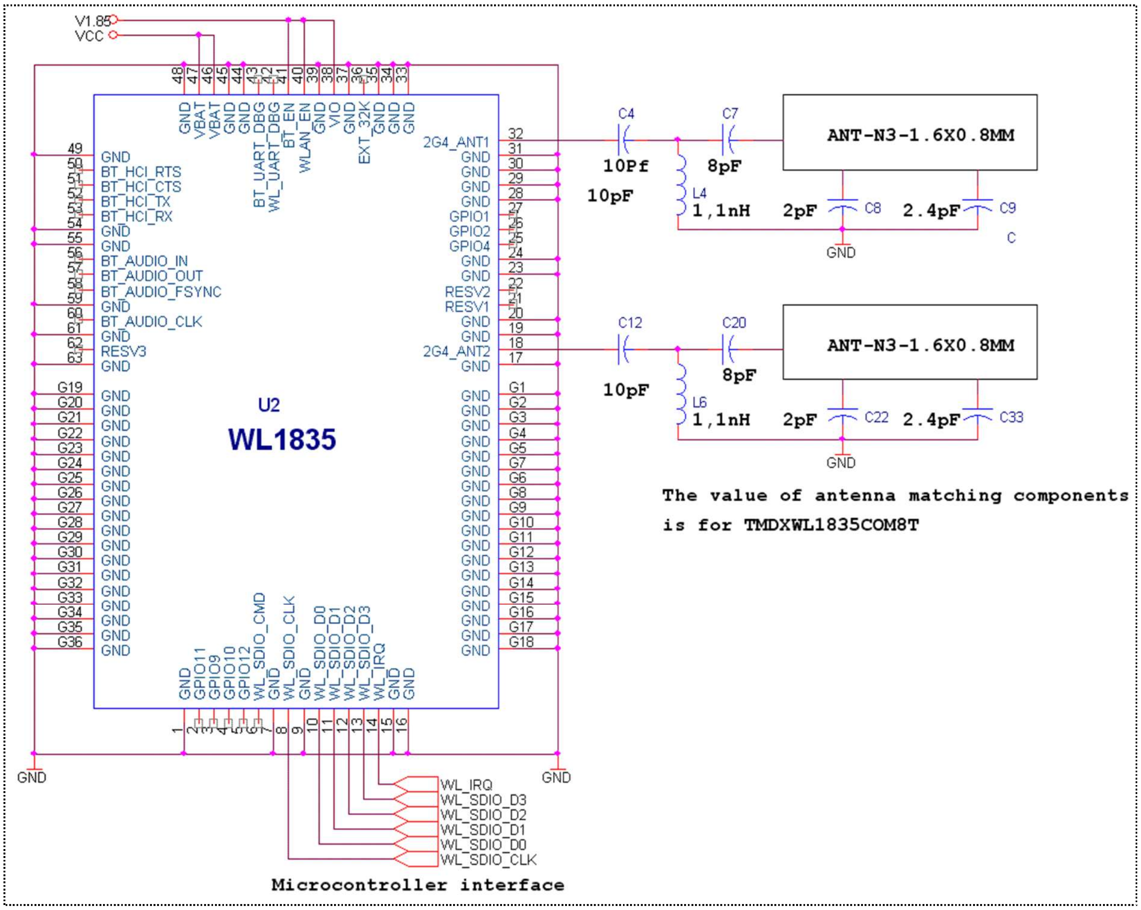
The microcontroller,

which is responsible with the whole unit functionality. We decided to use an ARM CortexM3 chip, working at 80 MHz internal, based on a 16 MHz external quartz and internal frequency multiplier, PLL based



32 mbytes DRAM memory.

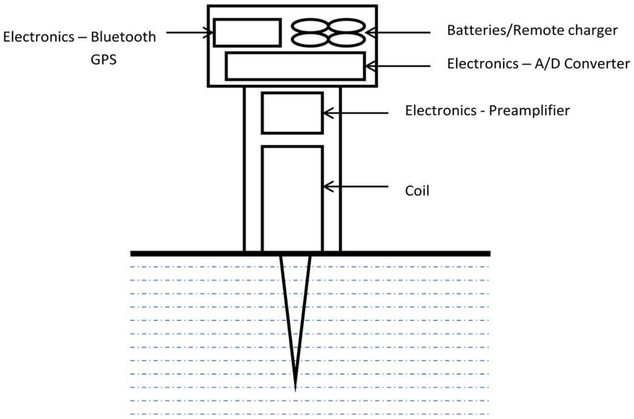
The refresh operation is done by microcontroller, based on an internal timer and the associate interrupt routine.

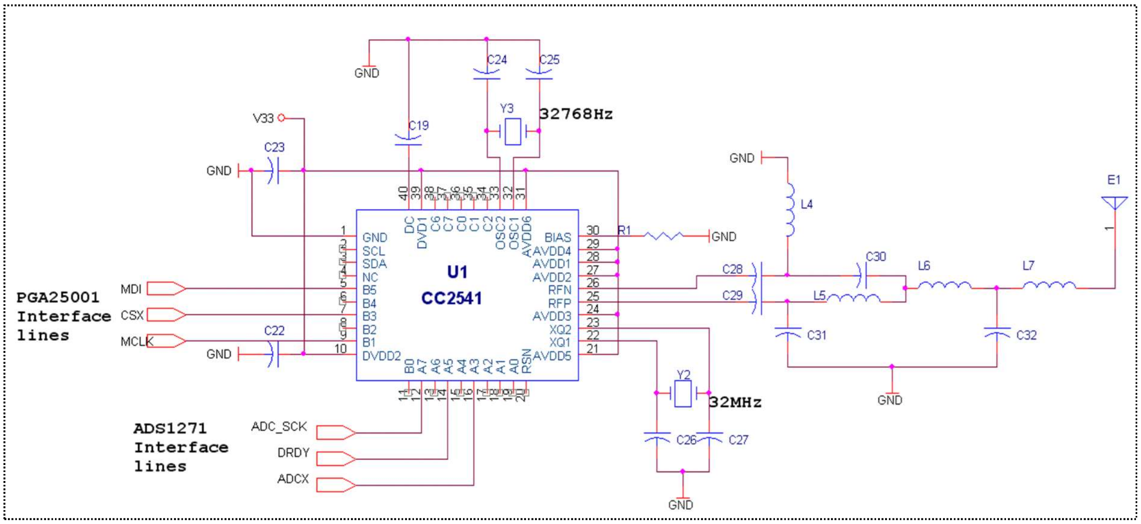


The WiFi (Dual Channel) and Blue Tooth interface is provided by an WL1835 chip from Texas Instruments. The communication between this chip is made by a four line serial interface, very similar to a ETHERNET connection.

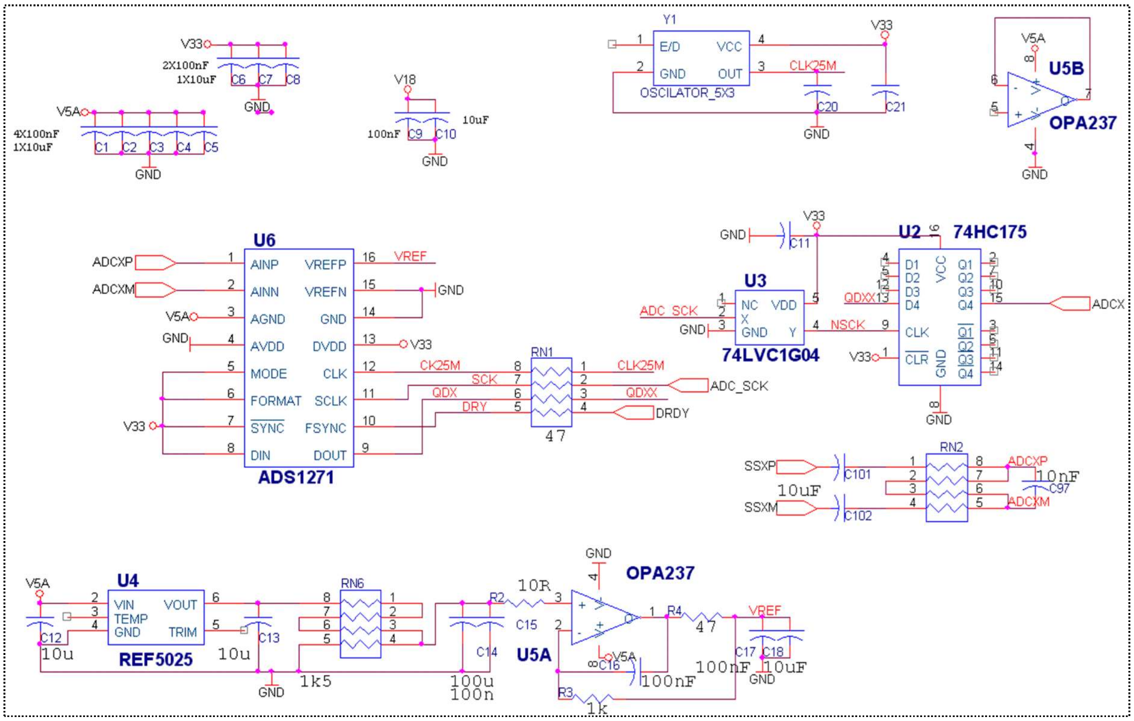
10.3. Wireless Land Geophone (WLG)

Wireless Land Geophone (WLG)

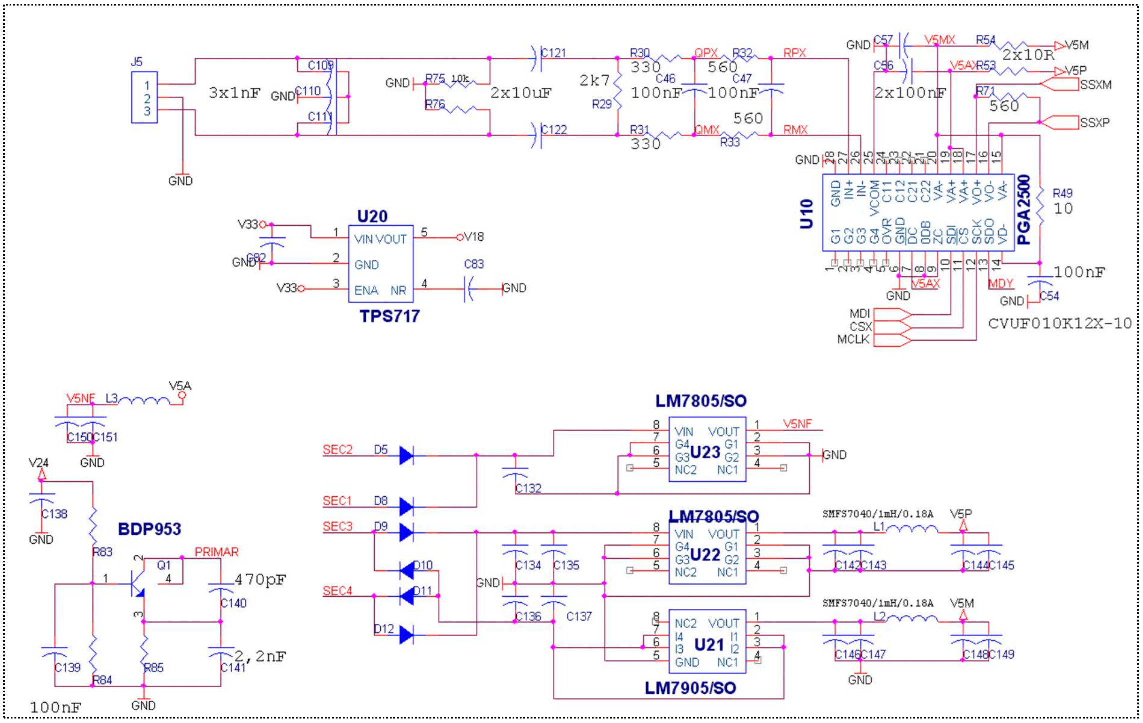




Each independent geophone unit is ruled by a Blue-Tooth one chip controller. The Texas Instruments CC2541 has a 8051 Core and all RF necessary circuits and firmware to implement Blue Tooth

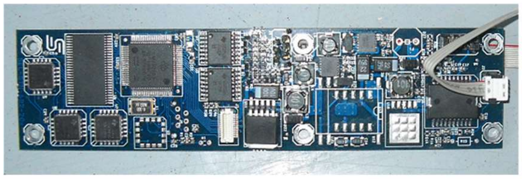


The element unit has an 24 bit ADC, Texas Instruments, ADS1271

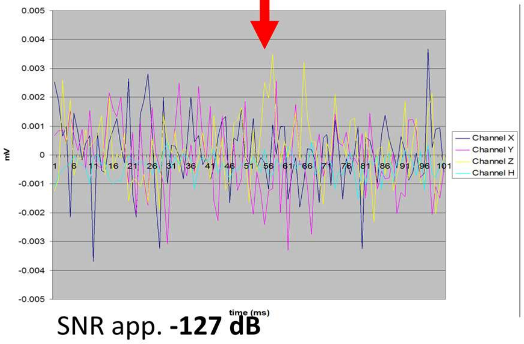


In the element unit, the geophone data is amplified by the PGA2500 circuit.

10.4. Testing

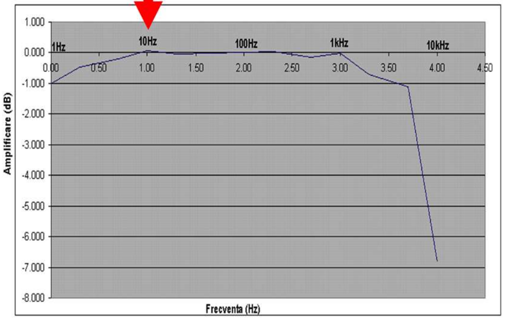


Testing operations
Functional testing of the analogue module
Test of the power supply of the module
Measurement of the noise – analog channel
Measurement frequency response – analog channel
Measurement of the linearity– analog channel
Measurement ADC conversion errors



SNR app. **-127 dB**

(1.2µV at 1800 Hz bandwidth)



10.5. Some of the Hardware Components chosen

10.5.1.802.11ac System on Chip (SoC)

Texas Instruments

Texas Instruments produces the WL18XXMOD WiLink chips family.

Main Features:

- General
    - Single WLAN Module Integrates RF, Power Wi-Fi in One Step Amps, Crystal, RF Switches, Filters, Passives
    - Temperature Compensation to Minimize Variation in RF Performance Over Entire Temperature Range
    - Operating Temperature: –20°C to 70°C

- Small Form Factor: 13.3 × 13.4 × 2 mm
- 100-pin MOC Package

- Wi-Fi
  - WLAN Baseband Processor and RF Transceiver Support of IEEE Std 802.11b, 802.11g, and 802.11n
  - 4-Bit SDIO Host Interface Support
  - 20-MHz 2 x 2 MIMO and 20- or 40- MHz Channels for High Throughput: 80 Mbps (TCP), 100 Mbps (UDP)
  - Wi-Fi Direct Concurrent Operation (Multichannel, Multirole)
- Bluetooth and BLE (WL183xMOD Only)
  - Bluetooth 4.0 and CSA2 Support
  - Dedicated Audio Processor Support of SBC Encoding + A2DP
  - Royalty-Free Certified Stack From StoneStreet One
- Key Benefits
  - Reduces Design Overhead
  - 1.4X the Range Versus a Single Antenna
  - Differentiated Use-Cases by Configuring WiLink 8 Simultaneously in Two Roles (STA and AP) to Connect Directly with Other Wi-Fi Devices on Different RF Channel (Wi-Fi Networks)
  - Lowest Wi-Fi Power Consumption in Connected Idle (< 800 µA)
  - Wi-Fi-Bluetooth Single Antenna Coexistence
  - Available as Easy-to-Use FCC, ETSI, and Telec-Certified Module
  - AM335x Linux® and Android™ Reference Platform Accelerates Customer Development and Time to Market

10.5.2. Memory medium for Data Storage

There are several technical characteristics that the chosen data storage media should have:

a. Non-volatile: data should be retained in case of power failures;
b. Small dimensions;
c. Large range of operating temperatures, e.g. -40° to +85 °C;
d. Fast transfer speeds;
e. Large number of read/write operations or hours of usage

After studying the 3 standards available: FAT16, FAT32 and NTSC we opted for FAT32 for the following reasons:

- The FAT structure is simpler.
- The FAT folder size is smaller for an equal number of files.
- FAT has no controls regulating whether a user can access a file or a folder; therefore, the system does not have to check permissions for an individual file or whether a specific user has access to the file or folder.

A FAT folder entry contains an index of the file allocation table, which identifies the cluster number for the first cluster of the folder. To view a file, FAT has to search the folder structure.

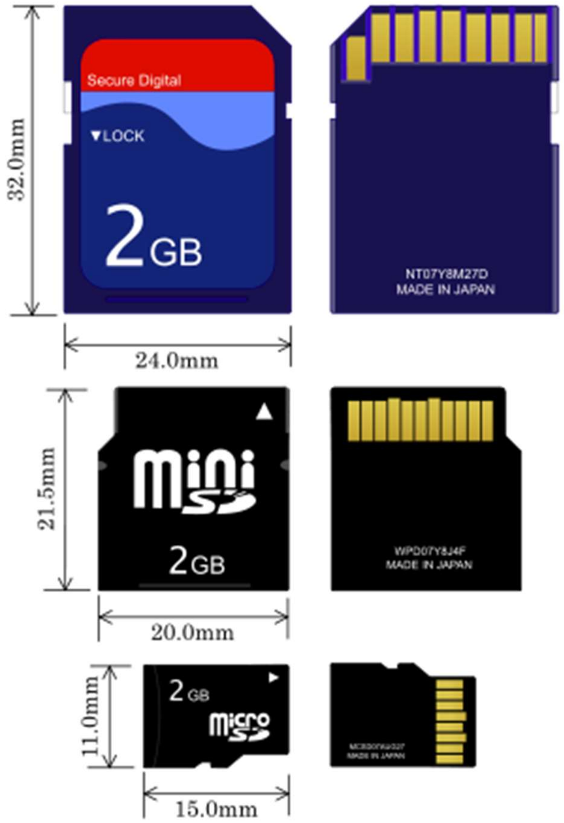
In comparing the speed of operations performed on large folders containing both long and short file names, the speed of a FAT operation depends on the operation itself and the size of the folder. In mathematical terms, the average time to find a file on a FAT folder is a function of $N/2$, where N is the number of files.

Maximum Sizes on FAT32 Volumes

The FAT32 volume must have at least 65,527 clusters. The maximum number of clusters on a FAT32 volume is 4,177,918. Table 3.11 lists FAT32 size limits.

Table 3.11 FAT32 Size Limits

Description	Limit
Maximum file size	$2^{32} - 1$ bytes
Maximum volume size	32 GB
Files per volume	Approximately 4 million



Dimensions:

Standard: 32.0 × 24.0 × 2.1 mm

Mini: 21.5 × 20.0 × 1.4 mm

Micro: 15.0 × 11.0× 1.0 mm

http://en.wikipedia.org/wiki/MicroSD#microSD
http://www.nextpowerup.com/news/1645/sandisk-extreme-series-micro-sd-cards-offer-blistering-fast-80-mbps-speeds.html

Card	Seq. Read	Seq. Write	Random 512K Read	Random 512K Write	Random 4K Read	Random 4K Write
SanDisk Extreme 32GB	40.08 MB/s	32.2 MB/s	36.1 MB/s	4.7 MB/s	2.24 MB/s	0.44 MB/s
SanDisk Ultra MicroSD 32GB	40.7 MB/s	10.4 MB/s	38 MB/s	1.7 MB/s	3.2 MB/s	0.58 MB/s
SanDisk Extreme MicroSD	41.9 MB/s	34 MB/s	39.4 MB/s	25 MB/s	4.5 MB/s	0.98 B/s

Card	Seq. Read	Seq. Write	Random 512K Read	Random 512K Write	Random 4K Read	Random 4K Write
64GB						

10.5.3. Data Compression

2.5 Gbits/sec GZIP Compression/Decompression IC

The AHA3610 GZIP compression coprocessor is a single chip CMOS VLSI device that implements the open-source GZIP (Deflate) lossless data compression and decompression algorithm. It supports a simultaneous compression/decompression data rate of 2.5 Gbits/sec, while achieving compression performance equivalent to GZIP S/W. The device implements 2 high speed 16-bit parallel DDR interfaces for easy integration in to many microprocessor based systems.

Features

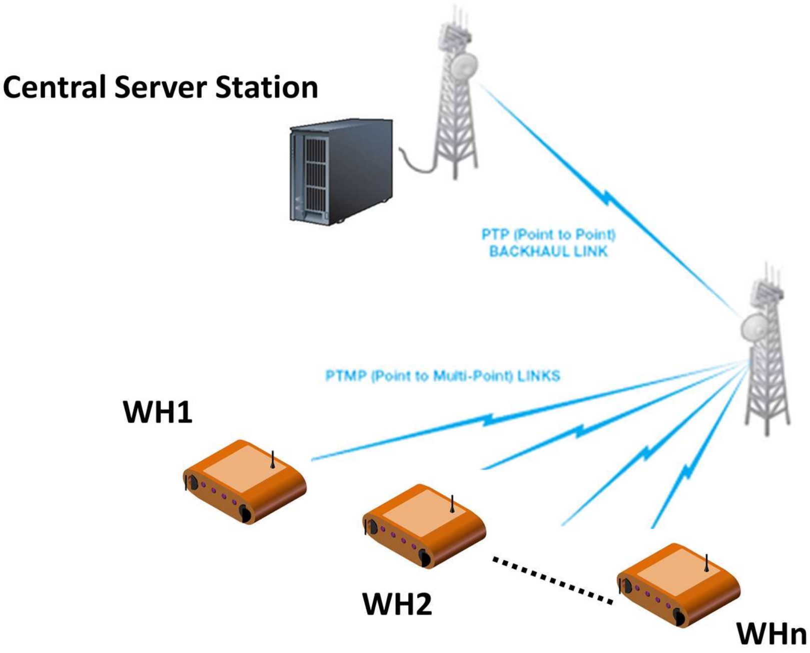
- 2.5 Gbit/sec compression/decompression rates
- Full GZIP/Deflate algorithm compliance
- Compression performance equivalent to GZIP S/W
- Simultaneous compression and decompression
- Low Latency (4K segments < 24 usec)
- 529 pin fine-pitch BGA package
- RoHS compliant

http://www.aha.com/DrawProducts.aspx?Action=GetProductDetails&ProductID=13

10.5.4. Radio Equipment for the Long Distance Transmission (between Field Network and Central Server)

Ubiquiti RocketM2: 802.11N 2 GHz 2x2 MIMO AirMax TDMA Base Station

Ultimate in RF Performance:
The Rocket is a rugged, hi-power, very linear 2x2 MIMO radio with enhanced receiver performance. It features incredible range performance (50+km) and breakthrough speed (150+Mbps real TCPI/IP). The device was specifically designed for outdoor PtP bridging and PTMP Airmax base-station applications



Rocket M Seamlessly Integrates with AirMax BaseStation and Rocket Antennas:
Rocket M and AirMax BaseStation/Rocket Antennass have been designed to seamlessly work together. Installing Rocket M on AirMax BaseStation/Rocket Antennas requires no special tools, you simply snap it into place with the mount provided with the RocketDish or AirMax Antennas.

The Rocket M easily and securely snaps into place on Ubiquiti Carrier-Class Antennas

The Rocket Dish 2G-30 Antenna or any of the AirMax 2 GHz antennas.

AirOS V: Version 2 of Ubiquiti's AirOS builds upon the market leading intuitive user-interface loaded with advanced wireless configurations and routing functionality.

Features:

- High Performance MIMO 2x2 TDMA Architecture
- Extended Outdoor Range
- Ubiquiti AirOS software
- External status LEDs
- External reset button
- Pole, Wall or Window mount options

Specification:

- 27 dBm +/- high power 802.11N Atheros SOC
- MIPS 24KC, 400MHz
- 64MB SDRAM, 8MB Flash
- 1x10/100 Base-TX (Cat%, RJ-45) Ethernet Interface
- FCC Part 15.247, IC RS210, CE
- Rx Sensitivity: -94dBm +/- 2 dB
- RF Connector: 2 x waterproof RP-SMA
- Maximum Power Consumption: 8 Watts
- Dimensions: 16cm x 8cm x 3 cm
- Weight: 0.5 Kg
- Enclosure: Outdoor UV Stabilized Plastic
- Pole Mounting Kit included

- Power Supply: 24V, 1A POE Supply included
- Power Method: Passive PoE (pairs 4,5+: 7.8 return)
- Operating Temp: -30C to +75C
- Shock and Vibration: ETSI300-019-1.4
- RoHS Compliant: Yes

For full data brochure please access:
http://dl.ubnt.com/datasheets/rocketmgps/Rocket_M_GPS_Datasheet.pdf