Confidence in data recorded with land seismic recorders

Nicolas Tellier[1*] and Steve Wilcox[1] discuss how land recorders have evolved and the impact of quality control.

Introduction

Seismic contractors and their clients constantly strive to increase the productivity of land seismic acquisition projects, and this combined with a trend for denser receiver geometries is resulting in much larger volumes of data being acquired on a daily basis. This has created a challenge for the checking of data consistency and its suitability for imaging, and has led to new approaches to in-field quality control.

In addition, land seismic recording equipment has been evolving, creating divergences in the way that different systems operate, and three categories of land systems have emerged that can be separately identified – cabled systems, wireless systems, and cross-technology systems. These different classes of systems have distinctive approaches to in-field quality control capabilities, associated with their philosophy and architecture – QC may be acquired in real time, it may be collected from the equipment in-field with some field crew effort, or indeed there may be no QC acquired at all. Some equipment manufacturers insist that with the greatly improved reliability of modern electronics, monitoring of QC during seismic acquisition is no longer of importance. However, for most seismic contractors and the great majority of their clients the reassurance provided by QC monitoring is an important aspect of the operations.

In this paper, we firstly discuss how land recorders have evolved and the impact of QC, then describe the different categories of land systems focusing principally on their QC capabilities, and finally discuss the operations of QC during acquisition projects.

A brief history of land recorders

A technological uplift

From the origins of reflection seismic, land seismic recording systems have traditionally used cables to interconnect the seismic signal from the geophones to a central recorder; initially in analogue form, and then digitized at or close to the geophones. With increasing channel counts, the management of the cables, including repairs to damage caused by vehicles, livestock or wild animals, was recognized as becoming a significant operational challenge. A few attempts at developing radio-based recorders were made in the 1980s and 1990s with limited success (Tims, 1983). The Fairfield Box and Opseis Eagle are two examples of systems that used narrow-band VHF radio to transmit data from field digitizers to the central recording unit. The Input/Output RSR system took a different approach, using its VHF radio system to control acquisition and to transfer QC data from the field units to the central unit, with the seismic data being recorded locally at the field unit for transcription at a later time. The I/O RSR was in widespread use in North America until around 2009.

From around 2008, technological advances enabled by low-cost GPS receivers, bulk flash memory, high energy density lithium batteries and new wireless technologies led to the introduction of a new generation of cable-free systems. These became so successful, that they have almost completely replaced traditional cabled systems in North America, although this success has not been completely replicated worldwide, where, in the years 2011-2015 wireless systems accounted for approximately 25% of the world market for land seismic systems. In 2013, another new type of system was introduced whose architecture is referred to as cross-technology. This type of system blends the features of cabled and wireless systems. It has the capability of operating in the same way as a conventional cable system. However, it can also be configured to operate and record autonomously, with data being recorded into field equipment rather than being transmitted to a central recording unit.

What should we understand by QC

As the demands of denser acquisition designs and higher productivity have increased (Figure 1), so the concept of quality control in acquisition projects has evolved. Statistical analysis of groups of shots, correlated to the topography, and tools such as in-field, real-time PSTM updated every shot (Cotton, 2016) have replaced traditional methods such as visual checking of each shot gather. Additionally, as electronics have become highly reliable, the quality control of the equipment has become more of a test of condition and compliance for operations – battery state, GPS status, geophone tilt – than of failure detection. The evolution of land system architectures has resulted in divergences in the usage of terminology, and the definition of 'Quality Control' now varies between types of land system and manufacturer. In cabled systems, the term generally retains its traditional meaning, covering both seismic data quality and equipment functionality, however, in wireless systems its use is generally restricted to equipment functionality with occasional inclusion of some field parameters such as ambient field noise. Indeed, some wireless

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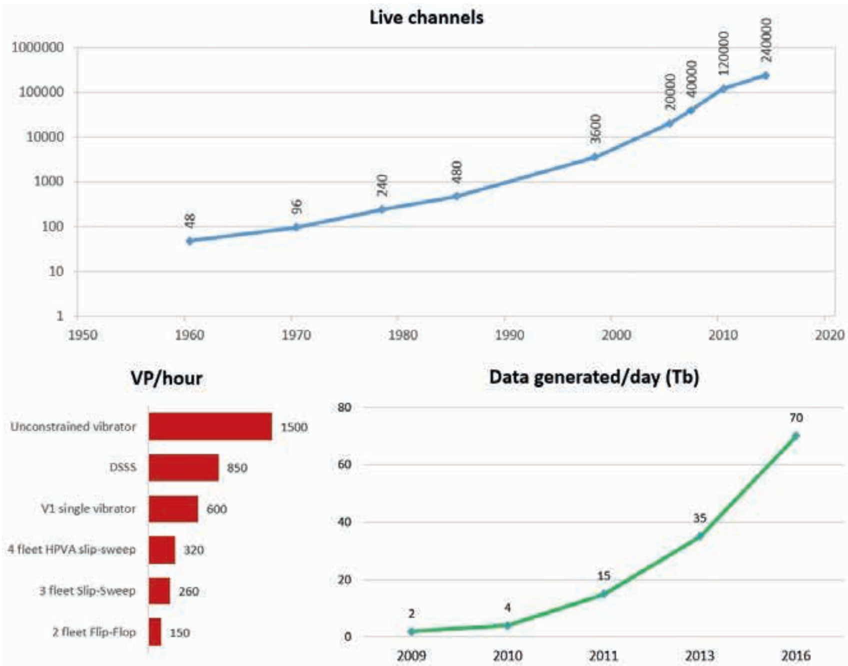

Figure 1 Evolution of land acquisition parameters. Increasing channel count and productivity generates more data: its QC has to be adapted.

system manufacturers insist that no quality control is required during acquisition as equipment reliability is at such high levels, and no provision is made for the operator to monitor it. This concept of readiness and compliance for operation for wireless recorders will be referred to here as 'Operation QC'.

It is the contention of the authors that many land seismic contractors, and the majority of clients value, and benefit from, quality control monitoring during acquisition, and in this paper we review the main current families of land systems and how they address the quality control issue.

Land recorder families and QC management

Cabled recorders

Cabled recorders have, by their very design, a fixed high bandwidth communications channel from the field equipment to the central unit (Figure 2). The primary purpose of this channel is, of course, to transmit data to the central unit for recording, but is also used to communicate QC information in real-time. The cost for the high level of confidence that this provides is the management of the cables and their susceptibility to line cuts. As survey densities increase and channel counts rise, this susceptibility is becoming an increasing concern, and this, together with commercial pressures towards higher productivity levels, is being brought very strongly into focus in the current context of very low acquisition prices and strong competition.

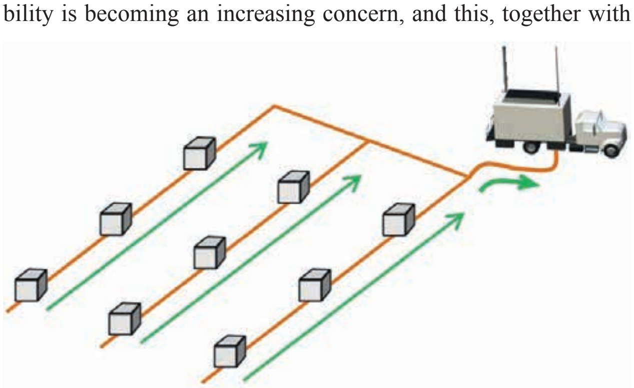

Figure 2 Cable recorders have a centralized architecture: seismic data and QC are available in real-time.

Wireless recorders

Within the category of wireless recorders, four distinct classes can be identified. These are differentiated by the scope and method of QC monitoring:

- Real-time wireless recorders automatically transmit operation QC (e.g., battery state, GPS status, geophone tilt) and field noise to the central unit with a short latency, together with seismic data. Functionally, these systems (Figure 3) use a dedicated infrastructure to have the capacity to transmit the large seismic data. They are similar in operation to cabled recorders, and have similarly susceptibility to wireless links being interrupted.
- Remote QC wireless systems do not provide a means of transmitting seismic data to the central unit, but do provide, for example, a low bandwidth communications channel in the form of a dynamic, self-organizing mesh network, in order that operation QC can be transmitted in near real-time to a central monitoring station (Figure 3). Each field unit in this class of system monitors its own operation QC as well as the level of ambient field noise and transmits an alert message to the central monitoring station as soon as an out of tolerance condition is detected. Seismic data can also be collected, with some field effort, by personnel travelling on the spread.
- QC Capable wireless systems (Figure 4) provide no communications channel to the central unit for seismic data or operation QC but do provide a wireless communications method to enable the collection of operation QC (and to a lesser extent, of seismic data) by field crew during acquisition. This requires some field effort, as personnel are required to travel on the spread to collect the QC data. The extent of the field effort is variable between manufacturers depending on the detailed implementation of the system.

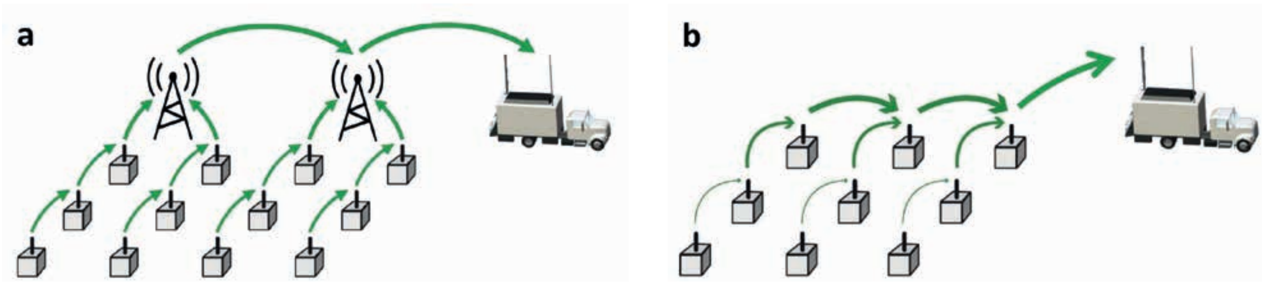

Figure 3 Real-time and remote QC wireless recorders can be based on two architectures: (a) relay antenna backbone and (b) multi hops.

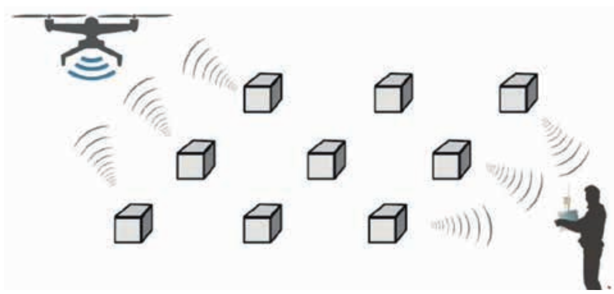

Figure 4 QC capable wireless recorders: seismic data and QC can be harvested on the field.

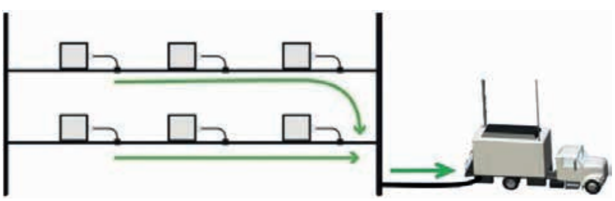

Figure 5 Blind wireless recorders: QC available only through physical connection (usually on racks) after modules are retrieved from the field.

- Blind recorders, normally fully integrated, internal sensor nodes with no, or extremely limited wireless connectivity provide no means for the collection of operation QC or seismic data during operation. This is not available until the field units are collected, transported to a transcription centre and their data downloaded (Figure 5).

Wireless recorders are now accepted, and even considered as mandatory for projects with significant access issues, but the way they manage operation QC varies considerably (Table 1). It should be noted that all types of wireless recorders require a large quantity of batteries (normally one per channel instead of one for several tens of channels), which complicates field logistics in the case of external batteries. Additionally, their maintenance and eventual replacement, increases the equipment cost of ownership as the average lifetime of batteries is far below that of the electronics.

Cross-technology recorders

The latest family of land seismic systems integrates concepts from both cabled and wireless systems (Figure 6). With intelligence, GPS timing, and memory integrated into field units, these systems are able to operate in a variety of different ways within the same spread. If fully interconnected with the cable (Figure 6b), they operate in an identical manner to traditional cabled systems, with seismic data and QC being communicated in real-time to the central unit. In the event that a section of the spread is separated from the rest by an obstacle, such as a river or a highway, that section can be operated as an autonomous section (Figure 6a), with data being recorded locally for harvesting by the field crew at a convenient time. In this case, there is the facility to connect a low-bandwidth wireless QC radio link, so that the autonomous section resembles a Remote QC wireless system. Of course, if the system is being operated as a cabled system, it is likely that at some point a cable cut will occur, isolating a section of the spread (Figure 6c). If this happens, the isolated section continues to record as an autonomous section. Seismic data and QC are transmitted to the central unit when the line is repaired, but it is also possible for the field crew to collect QC and harvest seismic data from the section in a similar way to that in which QC capable wireless systems operate. Thus, the architecture of cross-technology recorders can be seen to incorporate aspects of all current cabled and wireless land system types, and of course, it is straightforward to operate wireless nodes with them on a project if required (Figure 6d).

	Seismic data			Operation QC		
	Real time	Field collection	Transcriber download	Real time	Field collection	Transcriber download
Real-time wireless	✓	×	×	✓	×	×
Remote QC wireless	×	✓	✓	✓	✓	✓
QC capable wireless	×	✓	✓	×	✓	✓
Blind recorders	×	×	✓	×	×	✓

Table 1 Seismic data and operation QC: management capabilities of the different classes of wireless systems.

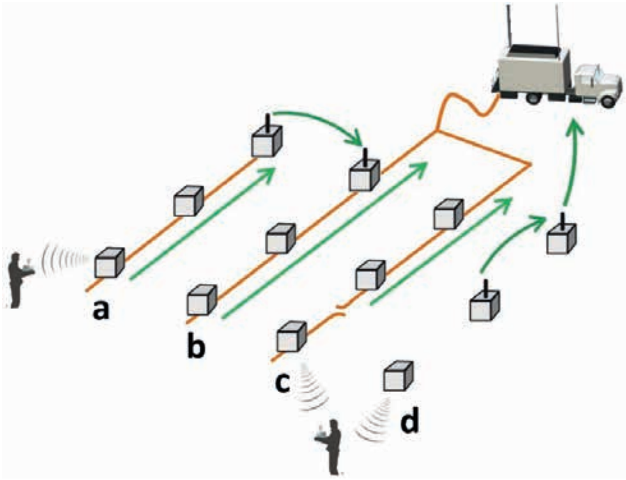

Figure 6 Cross-technology recorders mix the possibilities described in figures 2 to 5 within the same spread: (a) autonomous line with no physical connection to the central unit, (b) cabled line connected to the central unit, (c) cables line with line cut and (d) line of wireless channels.

In the following section of the paper, we focus on the most common techniques used to collect QC from QC capable, remote QC and cross-technology system types in order to demonstrate the inherent flexibility of these methods.

Wireless systems supporting QC in practice

The experience of the authors, based on interactions with seismic contractors and oil company clients worldwide, is that at the present time a majority of operators require at least a minimum of field equipment condition and noise level monitoring during acquisition. The reasons given are numerous; for instance, the noise level should be monitored when shooting with explosives (no noise mitigation possible as with Vibroseis correlation and stack), reducing source and receiver array geometries making data quality more sensitive to ambient noise, or the risk of having a significant quantity of nearby channels moved or damaged in agricultural or inhabited areas.

In this regard, the sections below present practical considerations about QC collection for the land recorders supporting it: how QC data are collected in practice with different technologies of recorders, and discussion about the limitations of different technological choices.

QC capable wireless systems

As previously mentioned, QC capable systems are designed to allow the operator to collect equipment QC during acquisition, but at the cost of some field effort. Some also provide for the collection of seismic data during acquisition with the same additional field effort cost. The QC is not available in real-time for the full spread, but with a delay that is dependent on the collection strategy adopted by the crew. The most common methods in use and their implications in terms of operation and quality confidence are described below.

Dedicated QC teams

To date, the method of using dedicated QC teams using mobile harvesters (Wilcox, 2013) to collect QC data appears to be the most widespread. The primary reason for this is the flexibility it offers to adapt to field constraints (e.g. topography, distance, permitting etc.) by varying the number, size and transportation means of the teams. An 8500 active-channel survey in France described by Baris et al. (2014) reported that around 50% of the field units were QC checked daily in a predominantly agricultural area with difficult access. QC teams often go by foot or in all-terrain vehicles around the survey area, but where appropriate boats or helicopters are also sometimes used (Figure 7).

As described by Wilcox (2015) drones are now also being used to collect QC on projects, and are especially useful in areas with difficult access. This emerging technology is likely to continue being of interest to seismic contractors as prices decrease and their capabilities, especially flight autonomy and payload, increase.

Opportunistic harvesting

As computer equipment development has progressed and become lower in weight, cost and power consumption, so the resulting improvements to QC collection equipment offer the potential for another method of QC collection. If all the field personnel and vehicles working on a project are equipped with miniaturized QC harvesters, the QC collection can be performed by them in the background while they are undertaking their primary tasks (Figure 8). Although this would not result in a systematic QC check it would nevertheless result in the bulk of the project being QC checked with no field effort and at minimal expense. It is

Figure 7 Dedicated teams on a QC capable wireless spread: walking, with drones, or using dedicated vehicles.

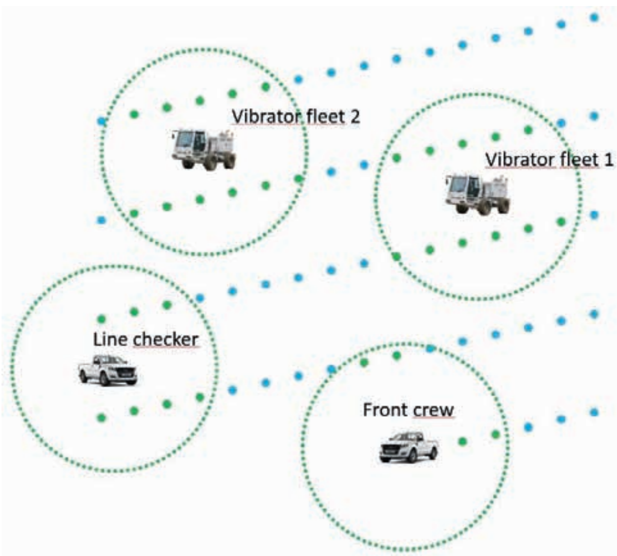

Figure 8 Opportunistic harvesting. Crew vehicles used for standard field operation harvest; the channel displayed in green with no effort.

not known if any projects are currently using this method, but it is probable, owing to the efficiency of this method, that it will be taken up by some at least as a complement to other methods.

Real-time QC on partial spreads

There are two other solutions which enable the collection of equipment QC and seismic data in real-time, but on a limited portion of the spread. One or more antennas can be set up on the prospect to establish a real-time wireless connection between channels within range of the antenna(s) (typically 1000 m) and the system server (Figure 9a). Alternatively, some contractors simply chose to deploy one or two lines of cable channels among their wireless spread (Figure 9b).

Among the methods described above, the use of dedicated teams is currently the preferred option for most seismic contractors owing to its flexibility, and the ability to more closely monitor the most exposed areas (i.e., subject to traffic or exposed to wind). Although this method is best suited to the collection of equipment QC, seismic data can also be collected this way for small configurations or on a predetermined portion of the spread, without significant field effort. Experience has shown, however, that most users progressively reduce seismic data harvesting during acquisition undertaking it only during channel roll, as their confidence in the equipment and systems of operation grows.

Remote QC and real-time wireless recorders

These two recorder types are able to automatically transmit information from the field units to the central unit with a reasonably short latency. Depending on the spread configuration, this latency may range from a few dozen seconds to a few minutes – thus such systems are more accurately described as 'near real-time' systems. The information transmitted typically includes field noise, as well as operation QC, including sensor status (e.g. tilt, impedance) and recording unit status (e.g. free memory capacity, battery level, GPS status). This information enables the observer and supervisor to monitor field operations and take timely corrective measures as and when necessary. In addition, real-time wireless recorders provide seismic data in near real-time, allowing more extensive QC during production. These two types of recorders generally operate either using a multi-hop network (information transferred from field box to field box up to the central unit) or through networks of relay antennas.

It is perhaps surprising that among the numerous wireless systems available on the market, only a minority have real-time features, when the standard inclusion of this functionality would close the current debate about the relevancy (or irrelevancy) of having operational status or seismic data in real-time. There is actually no doubt that if such features were available as standard, it would be used and valued, even if only for the confidence it would provide during operations. To understand the practical implications of real-time transmission, several technical aspects of recorder design have to be examined.

Cabled recorder designs are mainly based on proprietary technologies. The use of large telemetry networks, able to retrieve information from tens or hundreds of thousands of sensors in true 'real-time' even in the harshest environments is a problem unique to seismic exploration. It is different, however, for wireless systems. In the main, the technologies that drive

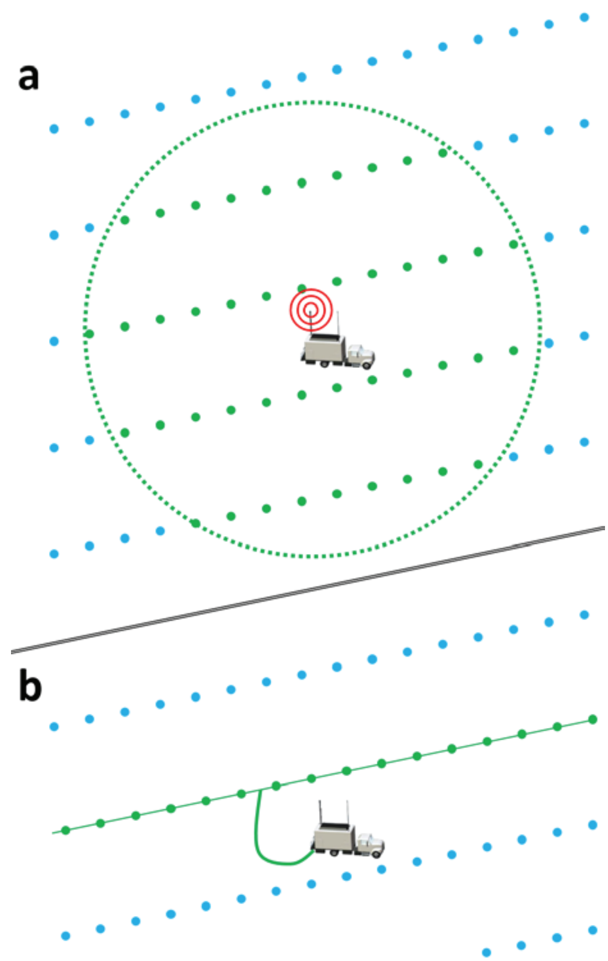

Figure 9 (a) seismic data and operation QC collection around recorder. Extra antennas (not represented) can be installed. (b) a wireless spread complemented by a cabled line. With these two solutions, both data and operation QC are available in real-time. Channels harvested are displayed in green.

their performance (e.g., battery autonomy and telecommunications) are open standard, and were developed for applications of a much larger scale than seismic. As examples, small and light high-capacity lithium battery technology has been led by commercial technology products such as cameras, mobile phones, and more recently electric vehicles; some wireless communications technologies used in wireless seismic systems were originally developed for commercial wireless broadband or for the 'Internet of Things'; and low cost GPS receiver technology is found in a myriad of consumer products. For equipment manufacturers, then, there are two principal challenges. The first is to find the right compromises in utilizing commercial technologies while still achieving seismic industry technical performance requirements. The second is to develop and integrate the necessary hardware and software to create high reliability systems while continuing to meet the demands and expectations of a wide variety of seismic industry end-users. The availability of open standard technologies means that there is a low technological barrier to entry into the seismic equipment market with wireless equipment for new entrants. However, meeting the challenges listed above demands significant experience of the specific requirements of the industry and established seismic equipment manufacturers would seem best placed to meet the challenges if they can be sufficiently innovative at adopting commercial technologies.

Here are a few examples of practical considerations and compromises that have to be taken into account when designing real-time transmission wireless recorders:

- The more data that is transmitted in real-time, the higher the power consumption and hence the lower the field unit battery autonomy.
- In multi-hop networks, the closer to the recorder, the lower the field box battery autonomy – especially when transmitting large amounts of data). Battery use is then not even over the spread, and so battery replacement has to be organized according to location of the field units in the network.
- Seismic data volume is extremely large when compared to QC. Seismic data transmission in real-time requires high-bandwidth links, which then, to maintain link margin, often require high gain antennas with narrow apertures (Figure 10a). This means that antennas have to be aligned, implying field preparation resulting in increased deployment time per channel. In particular, uneven topographies (Figure 10b) make field deployment challenging – three antennas at different elevations may not be able to be aligned, requiring the use of repeaters.
- Regulatory authorities limit the power emitted by radio systems. This limitation corresponds to the power of the transmitter plus the gain of the antenna, and all equipment manufacturers face the same limitation.

The transmission of high bandwidth data, such as seismic data, in real-time has a penalty both in power consumption (and, hence battery autonomy) and in field operations (and, hence operational expenditure). Although systems using real-time wireless transmission of seismic data have achieved some success in low-productivity, low-channel count configurations, the concept remains to be proven for current mainstream applications.

The approach taken in Remote QC systems is to use low bandwidth wireless networks to transmit the very much lower quantity of data required for the real-time transmission of QC. For example, these systems can transfer only a few status bits from each field unit indicating the functional status of the equipment. This approach is extended to field noise monitoring, where each field unit monitors the field noise and compares it to a pre-configured threshold, transmitting a 'field noise alert' if the threshold is exceeded rather than transmitting the value. In this way, the bandwidth requirements of the wireless communication network are minimized, which has many benefits for the system operator, who is still able to monitor the status of the field equipment and field noise. The power consumption of the field units (and hence, battery autonomy) is almost as low as blind systems, and omni-directional antennas without restricted aperture can be used, so deployment is simple and requires no additional field preparation (and hence, no additional operational expenditure).

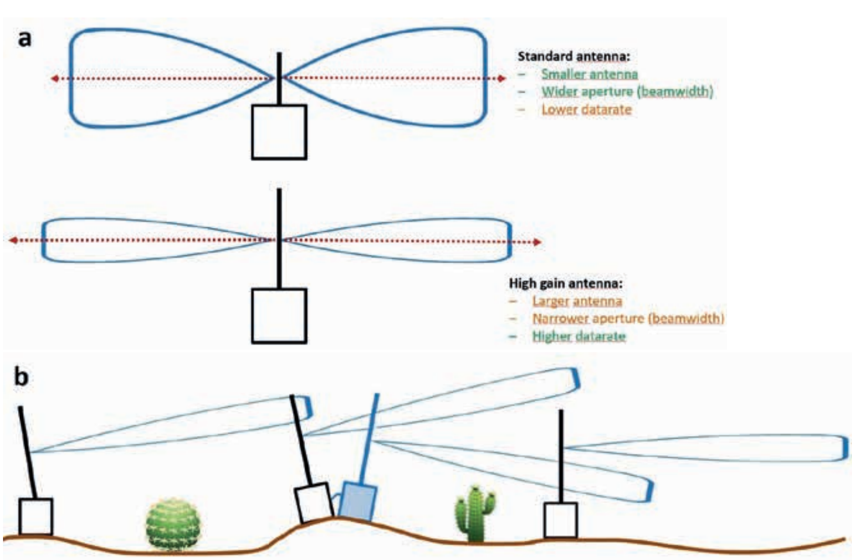

Figure 10 (a) comparative radiated power of a standard large aperture antenna (up) and high-gain narrow aperture antenna (down). Only major lobe is shown. (b) field preparation with narrow aperture antennas: antennas have to be aligned, and repeaters (blue) used in case of uneven topography.

Discussion and conclusion

With increasing requirements for denser geometries and higher productivities, the way in which QC is performed is evolving: single VPs are checked increasingly less often, while statistical approaches are more favoured for field data QC, regardless of the type of land recorder used. While field electronics are now highly reliable and no longer require to be checked for faults, it is observed, however, that it remains important for most oil and gas operators to have access to a minimum of QC from the field equipment within a reasonable amount of time. This QC is operational: monitoring field noise and checking the equipment layout condition and readiness enables timely decisions such as: 'can we start shooting' or 'can we start picking up this line'.

Land recorders QC capabilities in brief

- Cable recorders are sensitive to line cuts in exposed areas, but offer full QC (seismic data and operation QC) in real-time.
- Blind wireless recorders do not offer any field QC before being picked up and downloaded. They have achieved some success, especially in certain regions such as North America, but their use seems to have reached a plateau. Their use is, however, now considered in certain regions for high productivity acquisitions with limited concern for data quality.
- For QC capable wireless recorders, which currently represent the most widespread wireless option in the field, the use of dedicated teams to collect QC remains the most popular, and with the use of drones, significant simplification of the process is progressively being achieved.
- Remote QC wireless systems provide the operation QC and noise monitoring in real time, with no field preparation and almost no impact on field unit autonomy.
- Full QC (equipment condition and seismic data) is available in real-time with cabled recorders and real-time wireless recorders – for the latter, this capability implies significant compromises on other key performance aspects of the system, such as field preparation and autonomy.
- Cross-technology recorders blend features of the different land recorder technologies and in consequence can address most of the QC issues in real-time, hence providing a high degree of confidence in the data recorded.

Quality control… of which quality?

The current discussions concerning the performance of wireless land recorders mainly focus on cost and real-time capability. However, an important feature of recording equipment that seems to have slipped out of focus in recent times is the instrument performance of the acquisition electronics. With attention directed towards other aspects of performance, basic specifications such as noise floor (system ability to record weak signals) and instantaneous dynamic range (the noise-free range of signal amplitude that can be recorded, i.e., ability to record strong signal close to the source and weak deep reflections at far-offset) seem to have assumed reduced importance. Despite this, they remain fundamental to the central purpose of seismic recording equipment, which is to provide the best quality data in order to generate a clear image of the subsurface.

Concluding remarks

While the wireless real-time transmission of seismic data remains limited by existing technologies (in particular, wireless communications technology and battery autonomy), the industry is progressively getting closer to what appears to be the ideal answer to user expectations. That is, low power, wireless field equipment, which is cheap to operate and able to transmit both equipment QC and seismic data in real-time, without any need for additional infrastructure or field preparation.

This level of performance is, however, not to be expected in the near future so for now, cable recorders remain relevant for many projects – especially when the use of geophone strings is mandated, which removes many of the benefits attributed to wireless recorders. Cross-technology recorders, based on nodal architectures and enabling spreads with a combination of channels connected by cable to the central unit, cabled autonomous channels and wireless channels, are a solution that can adapt to any kind of environment and topography with a single system, and with no compromise to data quality.

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