

A review of nodal land seismic acquisition systems



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As the pages of this magazine will attest there is currently much interest in nodal land seismic acquisition systems. The benefits claimed within the marketing materials of such systems are many but just how do they stack up? And with the number of different systems reaching double figures how do they compare? In this article we give a snapshot summary of the various systems available, their relative pros and cons, a comparison with cabled systems and look at the geophysical implications of acquisition system choice.

Acquisition systems

During the early 1970s land seismic acquisition was conducted using analogue cable telemetry systems with analogue-to-digital conversion and recording (to tape) both taking place in the recording truck (Figure 1a). The seismic signal from each receiver station, expressed as the output voltage of a wired array composed of multiple individual geophone sensors, had an analogue electrical connection to the recording truck through a line cable with one 'takeout' connection per receiver station interval. Each receiver station required its own conducting wires within the line cable. These systems often used 'CDP cables', which incorporated additional conductors so that multiple cables could be joined end-to-end (Crice 2004). The number of conductors that can be included in a single physical cable led to a total number of channels that could be recorded being limited to approximately 1000 (Khan *et al.* 1982).

One approach to overcoming the limitations of analogue telemetry, first introduced in the late 1970s, is to use a radio telemetry system where the seismic data is digitised and recorded by individual boxes or nodes located in the field adjacent to the seismic sensors (Figure 1b). Recording is triggered using a radio link with data being retrieved either via the radio link or, more commonly, collected later manually (Aldridge 1983). Whereas analogue telemetry systems had

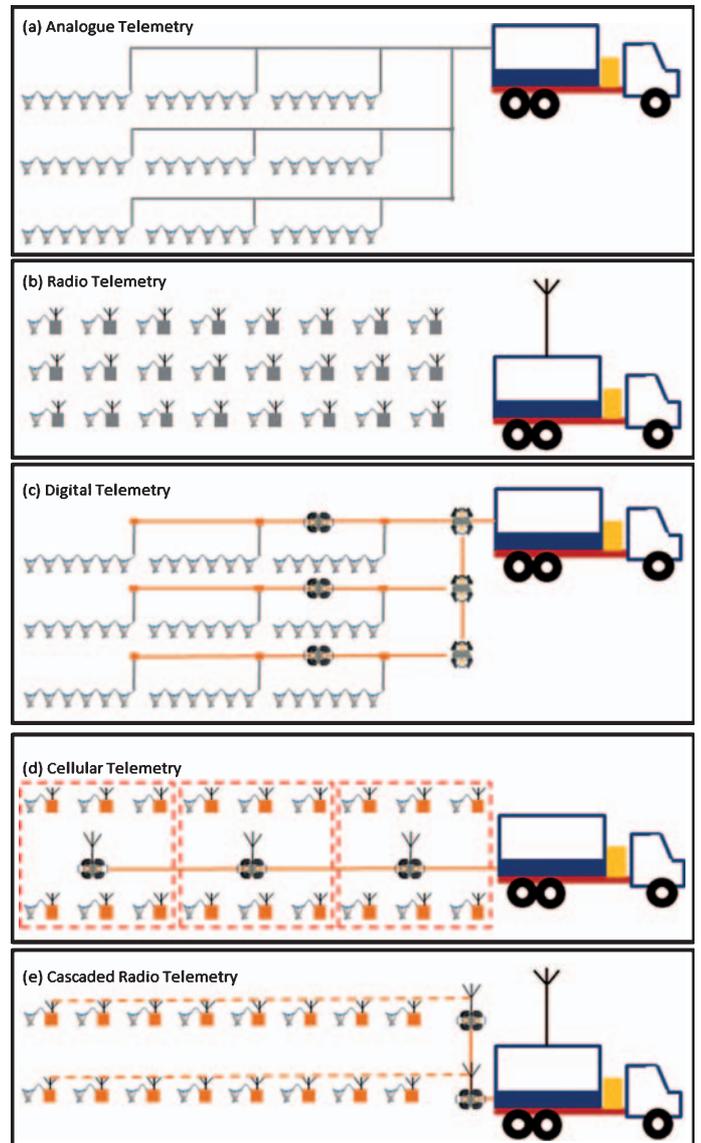


Fig. 1. Diagrammatic representation of different types of land source telemetry. Grey boxes and links indicate analogue, while orange indicates digital.

all the recording equipment located (and powered) in a central recording truck, the new system distributed the signal digitisation and recording functions out to equipment in the field. This avoided the limitations of analogue telemetry cables but brought new requirements to distribute power supply and sample time synchronisation to the separate field units. A distinction should be noted between 'data telemetry', where the full seismic data is transmitted (one-way) in near real-time to a central recording unit, and (two-way) 'command telemetry' where only time synchronisation between units, equipment status and parameter settings are managed by a central unit, the latter requiring considerably less bandwidth.

Another type of distributed system, introduced shortly after the introduction of radio systems, uses digital data and command telemetry over spread cables. This type of system has dominated

the seismic market for the past 25 years. Seismic data is digitised in field units that handle the inputs from one or more receiver stations, before being passed back to the central recording system via a hierarchy of additional field units that concentrate the data telemetry from multiple receiver stations and multiple receiver lines. For example, in-line boxes can be placed at intermittent positions along the cable to buffer the data and send it further down the line; these boxes also provide power to other components, such as digitising takeouts, if required. At the end of each line a cross-line box takes the data from the line and passes it via another cable, often fibre-optic, to the recording truck. Where the lowest level field unit handles only one receiver station it can be either a digital sensor package (for point-receiver systems) or a ‘takeout’ connection to attach a geophone array (as shown in Figure 1c). On some systems the lowest level field unit handles seismic data from more than one receiver station, for example, from four, six or eight stations, with analogue telemetry of the seismic signals from geophone array takeouts at each receiver station to the field units, then or at in-line boxes placed at frequent intervals.

As will be discussed further in a later section, radio telemetry systems have a variety of drawbacks. To overcome these, a cellular telemetry system called the *Infinite Telemetry System* or *it System*, was launched by Vibtech (now part of Sercel) in 2002 (Park and Flavell 2006). Data from the sensors is digitised at each individual node and then communicated via radio to an intermediate node that then sends data to the recording system via a fibre-optic link (Figure 1d). A further development of this system, introduced in 2006, was *Unite*, which allowed data, or a subset of the data, to be transmitted from the access nodes to the recording system directly via radio or collected (‘harvested’) later.

In recent years there has been a growing interest in ‘cable-free’ node technology. The definitions of these nodes are varied but can be broken into three groups:

- **Blind nodes:** nodes cannot communicate with the central recording system. Each node receives timing synchronisation via GPS. Data is saved locally and offloaded (harvested) when the node is picked up (similar to sub-sea nodes).
- **Radio QC nodes:** nodes send quality control information only to a central recording system via low speed radio infrastructure. Synchronisation is normally by GPS but can be distributed over radio. Data is saved locally and harvested when the nodes are picked up or periodically harvested via local radio or cable connections. Examples of the radio QC messages would be average RMS noise in the last 10 seconds, battery power remaining, memory capacity remaining, etc.
- **Full radio nodes:** nodes can send all seismic data in near real-time through high speed radio networks back to the central recording system. Synchronisation is normally by GPS but can be distributed over radio.

Blind systems

Blind systems have no data or command telemetry and record data onto local memory. GPS is used for timing and for synchronisation (although to reduce battery consumption they typically rely on an internal clock that is only periodically adjusted against GPS time). Data is recorded continuously over the period required and the shots are then extracted from the continuous data stream on download.

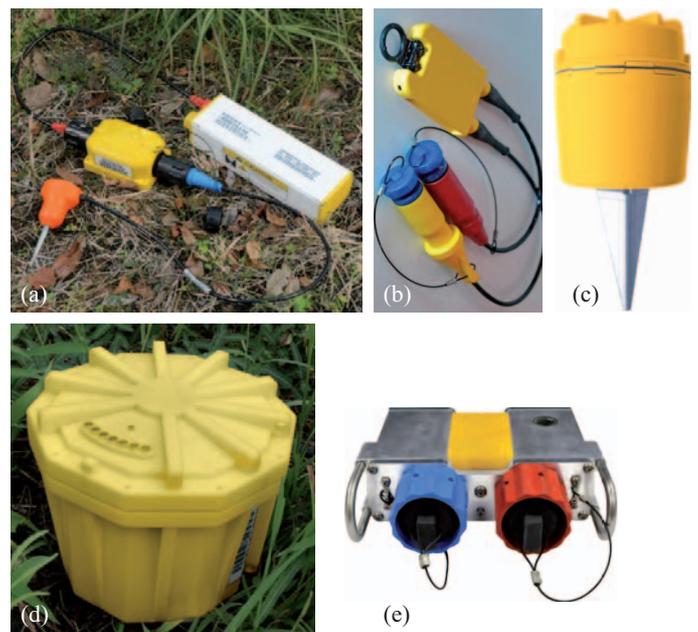


Fig. 2. Examples of blind recording systems: (a) OYO Geospace GSR with separate geophone, recording unit, and battery (courtesy of OYO Geospace); (b) AutoSeis HDR; (c) ZLand with all components integrated, the unit is 15.9 cm high without the spike (courtesy of FairfieldNodal); (d) the OYO Geospace GCX with all components integrated (courtesy of OYO Geospace); and, (e) INOVA Hawk SN11, only the recording unit is shown (courtesy of INOVA).

Blind systems give no real-time feedback as to their operation other than status lights on the units themselves. Data is usually downloaded manually from the unit when it is collected via a direct connection but the iSeis Sigma also has the option to use ruggedised memory sticks. These are the most common acquisition systems and include the OYO Geospace GSR (Figure 2a), the AutoSeis HDR (Figure 2b), ZLand (Figure 2c) and the OYO Geospace GCX (Figure 2d). The INOVA Hawk system (Figure 2e) also operates autonomously, but includes the ability to communicate locally with the line crew via Bluetooth and WiFi.

Typically most blind nodes are still operated with standard strings of geophones. In areas of high cable damage then many of the geophone may be cut or pulled out and this may go unnoticed for many days resulting in data degradation.

Radio QC nodes

Sitting between the real-time data systems and the completely blind systems are those that offer some form of real-time quality control. This category includes the Autonomous Recording Node (ARN) from Seismic Instruments (Figure 3a), which includes a radio to transmit a basic QC signal containing battery and memory status to the recording system. The INOVA FireFly system provides various trace attributes to QC the data as well as the sensor performance via a VHF or UHF radio link.

Full radio nodes

As mentioned above the first radio telemetry systems were developed in the 1970s, Shave (1982) stated that in the three years after its introduction in 1979 there were more than 20 crews each operating 200 *Opseis* ‘seismic group recorder’ units

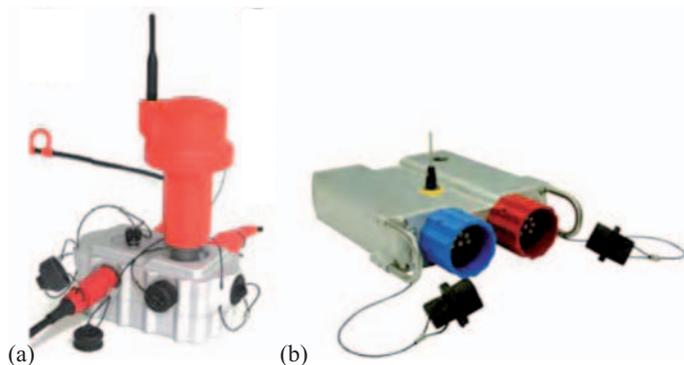


Fig. 3. (a) The Seismic Instruments Autonomous Recording Node (ARN) in red, contains the memory, battery and an antenna and is connected to the silver recording box; and (b) INOVA FireFly.

in the US. A survey of various people involved in Geophysics conducted in 1982 asked each respondent to predict when ‘25% of the seismic field systems in use will be dispersed, telemetry recording systems’ the average answer was 1996 (Hewitt 1983), but by 2010 nodal system sales (including, but not limited to, systems using radio telemetry) were only 5% of channels sold (Mougenot 2010). The reasons for the failure of these early radio-frequency systems can be summarised as (Heath 2003; Mougenot 2010):

- Radio requirements, sending large amounts of data in real-time requires a large bandwidth, typically in the already well-used VHF band. This results in both licencing and interference issues.
- High power consumption.
- Data recovery problems, if receiving data in ‘real-time’ the system may be delayed waiting for all the data to be sent or, if storing the data on nodes, the data may not be recoverable.
- Missing records, as the recording is triggered by radio.
- Higher cost including specialised components such as large antennas (Figure 4).

In addition to these issues, one of their initial motivations, that of being able to overcome the channel limits associated with analogue cables, was overcome by the introduction of the aforementioned digital telemetry systems. Although radio systems continued to be used through the 1990s (e.g. Sixma and van Der Schans 1994) they were limited to specialist applications such as mountainous terrains.

The more recent systems that utilise radio communications make use of the 2.4 GHz Wi-Fi radio band. This band is licence free and although power is limited, it is enough to communicate between closely spaced units. The RT system from Wireless Seismic (Figure 5) overcomes the limited range by sending data (‘bucket passing’) along a line of field units (Figure 1e). At the end of each receiver line the data is received by a line box that then transmits the data via a cable, or a radio operating on either 900 MHz or 5.8 GHz, to the recording truck.

The SERCEL Unite system (Figure 6) also uses the 2.4 GHz frequency band but each unit transmits data individually. Data can either be transmitted in real-time to an antenna (Figure 6b, maximum line-of-sight-range of 1000 m) or harvested periodically.

Units that include the ability to harvest or provide real-time data often also have the ability to record blind if the radio network

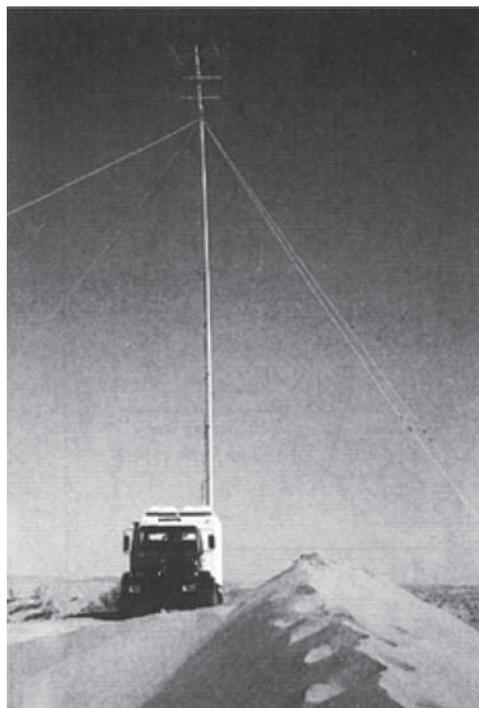


Fig. 4. The central recording system of an Opseis acquisition system acquiring data in China in 1994 (photo courtesy of the SEG). Note the large radio antenna.



Fig. 5. Wireless Seismic Wireless Remote Unit the yellow batteries are attached to the outside of the unit for easy replacement (photo courtesy of Wireless Seismic).

is disrupted. Not using functionality that has been paid for, both in cost and weight, is clearly undesirable, and the iSeis Sigma system overcomes this by allowing additional components to be

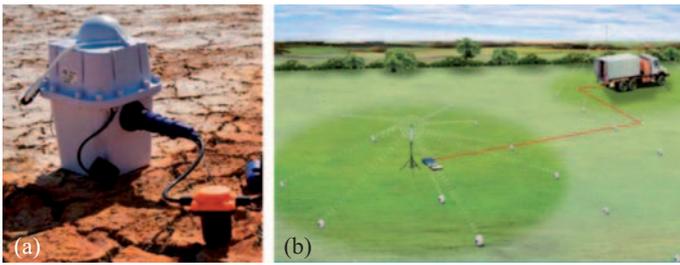


Fig. 6. (a) Sercel UNITE node with an internal battery and separate geophone string; and (b) diagram showing UNITE nodes sending data to a central node for transmission via a cable to the recording truck (images courtesy of Sercel).

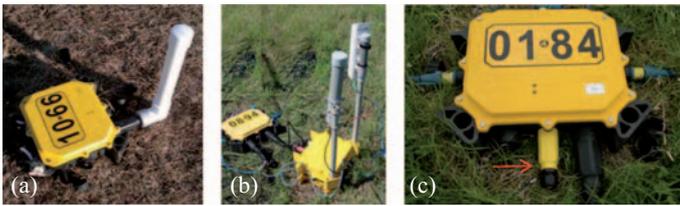


Fig. 7. Different configurations of the iSeis Sigma system: (a) with WiFi antenna; (b) with high speed backbone link; and (c) with external USB storage (all images courtesy of iSeis).

added to the basic node. For example, Figure 7a shows the unit with a WiFi antenna, Figure 7b shows the unit connected by cable and with a high speed backbone link and Figure 7c shows the unit with an external USB storage device.

Hardware configurations

All nodal systems consist of three basic components: the seismic sensor or takeout connection, a recording unit and a battery. Systems using some form of wireless telemetry also include an antenna. These three main components are variously combined into one, two or three separate packages. The most common configuration is to keep all three components separate, as in the OYO Geospace GSR (Figure 2a), INOVA Hawk (Figure 2e), iSeis Sigma (Figure 7), AutoSeis HDR (Figure 2b) and INOVA FireFly (Figure 3b). The Sercel UNITE system (Figure 6)

incorporates the recording unit, antenna and battery (although an external battery can also be added). The Wireless Seismic RT1000 unit (Figure 5a) is slightly different in that although it too incorporates the batteries they are placed on the outside of the unit and can thus be easily replaced. The FairfieldNodal ZLand system (Figure 2c) and the Geospace GCX (Figure 2d) have all three basic components combined in a single package, which makes them the only truly cable-less system. The Autonomous Recording Node (ARN) from Seismic Instruments (Figure 3a) is unique in that the battery, data storage (but not recording) and antenna are combined in a single unit that attaches to the recording box, which can also be used as part of a cabled system.

A summary of the attributes of each system is included in Table 1. There is wide variation in the weight of the systems (including the weight of the batteries) ranging from 1.6 to 17.2 kg. Generally speaking the blind systems are generally the lightest as they do not require additional radio infrastructure.

Batteries and system weight

The downside of nodal acquisition systems are requirements for GPS time sample synchronisation and batteries. To use GPS it is imperative that the units have good sky visibility and are not underwater or under wet soil or snow. As the sensitivity of GPS receivers improves and more satellite constellations are deployed then this problem should diminish and reliability should be acceptable for most field conditions apart from full water submersion. It is difficult to obtain power consumption figures for nodal systems but from what is available the consumption of simple autonomous systems is about twice that of the latest cabled systems (120 mW/channel for the UniQ system). Systems that use some form of communication have consumption values around four times that of the best cabled systems.

All the systems currently available use Li-Ion batteries whose performance is heavily dependent on temperature. Operating at extreme temperatures (<10°C or >50°C, a temperature easily achieved when batteries are left out in the sun) reduced not only battery voltages and capacity but also the life of the battery (Bloom *et al.* 2001; Zhang *et al.* 2003). Reductions in battery performance not only result in the need for more frequent charging but also add to the cost of the survey if their useable

Table 1. Operating mode: B, blind; RT, real-time data; WH, wireless harvesting; QC, quality control

Name	Manufacturer	Operating mode	Number of channels	Incorporates			Weight ¹ (kg)	
				Sensor	Battery	Unit	Battery	Combined
Z-Land	Fairfield Nodal	B	1	X ⁵	X	2.17	N/A	2.17
GCX	Geospace	B	1 or 3	X	X	2.72	N/A	2.72
RT Sys. 2	Wireless Seismic	RT	1 or 4		X	1.83	1.12	2.95
UNITE	Sercel	B/WH/RT	1,2,3		X	1.6/1.95 ²	N/A	1.6/1.95
GSR	Geospace	B	1,2,3,4			0.91	1.5	2.41
Hawk	INOVA	B	1,2,3			1.72	2.49/3.45 ³	4.2/5.2
Sigma	iSeis	B/QC/RT	1,2,3			3.20	2.1	5.3
HDR	AutoSeis	B	1 or 3			0.32	2.1	2.42
ARN	Seismic Instruments	B/QC/RT ⁴	max 72			2.2	15	17.2
FireFly	INOVA	QC	1,2,3			2.36	2.6	4.96

¹Excluding sensors. ²1-channel/3-channel versions. ³192 and 288 WHr batteries. ⁴Battery and memory QC only. ⁵This is the standard unit, an external sensor can be added if required.

life is shortened and battery lifetime uncertainty adds a large data loss risk especially when number of nodes increase per crew.

As can be seen from Table 1 the weight of the battery is between 40 and 90% of the total weight of the node (excluding the weight of the sensors). Using a 10000 channel crew recording for 12 hours/day as a benchmark the battery requirements for a nodal and a cabled system can be summarised as:

- Nodal system:
 - Battery duration: 14 days
 - Battery changes/day: 700
 - Battery charge time: 4–8 hours
 - Battery charging stations: 350 (based on 2 batteries/charger/day)
 - Total number of batteries: 15000 (+50%, Lansley *et al.* (2008))
 - Total battery weight: 30000 kg (2 kg/battery)
- Cabled system:
 - Battery duration: 12 hours (utilising solar panels)
 - Battery changes/day: 40
 - Battery charge time: 12 hours
 - Battery charging stations: 20
 - Total number of batteries: 80
 - Total battery weight: 2320 kg (29 kg/battery)

Comparisons of the weight of cabled and nodal systems vary in their conclusions. For example, Heath (2010) concluded that cabled acquisition systems are ‘under almost all conceivable circumstances’ always heavier whereas Lansley *et al.* (2008) considers that the weight of cabled systems is lower when the group interval is less than 50 m. For intervals of ~10 m, which are common for point receivers, his results show that the weight of a cabled system is only around 40% of that of a nodal system. Our own analysis shows that the weight of cabled systems when compared with blind (i.e. the lightest nodal) systems is lower at receiver intervals of less than 40 m, while for a receiver interval of 10 m the cabled system is only 24% of the weight of the blind node system.

Logistics

Since the majority of nodal systems still utilise geophone strings the day-to-day logistic effort of moving the spread is generally related to the crew’s channel count. With cabled systems there are fewer batteries to change but a larger number of telemetry cables to move; with nodal systems there is the addition of data harvesting. As the number of channels increases then the battery charging and harvesting effort of the nodes becomes larger than the logistics required on cabled systems. The majority of nodal systems require the unit to be retrieved and manually downloaded while systems that use wireless harvesting (e.g. UNITE) or USB drives (e.g. iSeis, Figure 7c) must still be physically visited. If units must be downloaded in camp then the unit is clearly unavailable for use in the field, requiring the purchase of additional units to enable the full channel count to be maintained. Downloading data is usually relatively quick (~5 minutes) but those units that have an integrated battery (Unite, GCX, ZLand) are unavailable until the battery is fully charged (typically between 4 and 8 hours).

In desert or snow-bound terrains equipment often gets buried; finding buried cabled equipment is quite straight forward, you simply follow the cables and recover it. Nodal systems are not so simple; those systems that are capable of communicating can ‘tell’ you where they are but those that are not can be difficult to find, putting both the unit and the valuable data it contains at risk. Although theft can still affect both cabled and nodal systems, with cabled systems at least the data has been recorded by the central recording system and is not lost as well. With cabled systems theft is observed in real-time by the observers when the system is operating. With blind node systems the risk is high as it may not be noticed for several days or even weeks that the nodes have been stolen. The UNITE system has a sophisticated tracking system (Lansley 2012) that enables stolen equipment, or at least the data, to be recovered but for the other systems there is no simple way of recovering them.

Geophysical considerations

When discussing seismic acquisition systems it must not be forgotten that the primary objective of a seismic survey is to sample the seismic wavefield. The choice of acquisition system, in particular the type of telemetry, is an operational matter not a geophysical matter unless it restricts sampling of the wavefield, i.e. the type of telemetry does not affect the seismic data if it has been acquired using the same acquisition parameters.

Previously, arrays of geophones were used to ensure adequate sampling of the wavefield while still working within the constraints of acquisition systems that could only record a limited number (<4000) of channels. The introduction of high-channel count (>100000) systems has allowed the arrays to be replaced by individually recorded sensors (‘point-receivers’) without spatially under-sampling the wavefield. Experience has shown that adequate spatial sampling often requires point-receivers to be around 10 m apart; at this spacing point-receiver nodal systems are an inefficient way to record such surveys. The receiver spacing at which the weight of nodal systems (as a proxy variable for efficiency) becomes less than cabled systems is ~40 m, a separation at which the data is unlikely to be sufficiently sampled. We could overcome this by using a closer source spacing but this would likely have serious operational implications, particularly if an explosive source is being used.

Discussion

The lack of success of early radio-telemetry systems can be attributed to their own technical limitations and the introduction of digital telemetry cables that removed one of their major motivations. Cable-less systems are often promoted as a light-weight, logistically simple, alternative to cabled systems but as discussed above they are only an advantage when the receiver interval is large. The logistics burden of maintaining cabled systems is replaced by the logistic burden of replacing batteries (although the impact of this burden is heavily dependent on terrain and temperature).

Cable-less systems are particularly advantageous when used in difficult terrain such as mountainous areas or cities. In areas where cable damage is an issue, for example from livestock, the use of cable-less systems only offers an advantage if point receiver data is acceptable (the use of arrays of geophones obviously providing plenty of geophone wire to be damaged).

Similarly many systems still include cables, for example between the recording system and the sensor and/or the recording system and the battery, which still require protection.

A move towards cable-less systems is also seemingly at odds with a move towards high-channel count dense point-receiver sampling (e.g. Pecholcs *et al.* 2012 and Lansley 2013). The logistics involved in downloading data and changing 10s of thousands of batteries a day is likely to be prohibitive. The future therefore, as suggested by Lansley (2012), is that there will continue to be surveys where the choice between cabled or cable-less systems is obvious, with some surveys benefiting from a combination of the two.

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