**Hybrid Cellular Seismic Telemetry System**  
**Robert G Heath**  
*Vibration Technology Ltd, Lord Hope Building, 141 St James St, Glasgow, G4 0LT, UK*

**SUMMARY**: The land and transition zone exploration industry faces a crisis. Reliable data transmission is the most essential ingredient for a cost-effective and expandable acquisition system. However, the technology it employs in this regard has changed little since the 1970's. Things must change if this industry is to have a successful future. A new system has been developed which will change land acquisition as much as the original digital systems did when they replaced analog hardware. The system has been demonstrated already in the UK. It permits massive reductions in cost of acquisition, allows increased data quality, and improved HSE. It is the most important step in instrumentation for a quarter of a century.

Figure 1: Cellular seismic system in use in UK. Vibroseis operation, 720 channels in 9 cells.

**INTRODUCTION**

During the 1970’s, the most common technology used in land seismic acquisition was analog cable telemetry. Each seismic channel used one pair of conductors to carry geophone signals from the take-out to the central system. Typical systems could handle counts* in the region of ~10^2 geophone channels. Every additional channel needed an extra pair of conductors. Therefore, it became difficult to handle the weight of analog spread cables and their bulky line connectors when larger crews were required.

Around a quarter of a century ago, distributed telemetry cable systems became available. Information from many digitised channels could be put onto just one or two pairs of wires which acted as a form of data bus. This did away with the need for two extra conductors for every additional channel. However, various factors still limited the amount of digital information which could be put onto one manageable spread cable for successful transmission back to the central system. Typical hardware could handle counts* of ~10^2 to ~10^3 channels. Later, systems started to be employed using 24 bit convertors, which increased reliability of the system as a whole, slightly reduced weight, and some of the latest such systems cope with ~10^4 channels*.

Nowadays, seismic data is not just used for 2D or 3D acquisition in virgin areas. End users will not pay “whatever it costs” and increasingly prefer to see their exploration budget put offshore where cost per sq.km, is much lower and data quality usually higher. Therefore, to survive, land acquisition now demands much lighter, more flexible and lower cost crews. It seeks a technology which can easily and cost-effectively handle >10^4 or 10^5 channels to permit, for example, single sensor or 3C acquisition, with lower HSE and LIS risk.

It does not seem likely that cable digital telemetry would easily fit the requirements due to considerations of weight, cost to buy and to operate, complexity and reliability. Therefore, a change in technology is required as soon as possible.

This paper describes a system which can extensively leverage existing technologies. It is the world’s first cellular seismic system, allowing a virtually limitless number of channels to be acquired cost-effectively, using significantly fewer personnel and vehicles, with less environmental impact and with relative logistical ease. These claims are based on tests carried out by other companies comparing differing

* Channel counts can exceed those indicated but this paper only discusses the order of magnitude of channel counts.*
telemetry systems and the effect they have on acquisition flexibility and productivity. It is also the world’s first hybrid system, enabling one system to work where previously either a cable telemetry crew worked, or an RF system had to be chosen.

THEORY

Cable acquisition systems tend to force users to treat the whole survey area as one problem rather than several independent “challenges”. This imposes limitations in productivity and viable crew size since the reliability of the system as a whole is related to the number of dependent and connected parts. Operations are labour-intensive, inflexible and several differing types of ground equipment can be required to cope with even small surveys. Such systems do not allow the survey area to be broken down into a number of identical, but much smaller sections using independent ground units, which can be much more easily handled.

Some while ago, the telecommunications industry had similar problems. There was a need for more versatile communications and increased capacity - giving freedom from being tied to a land line. This lead to the development of cellular telephony, where areas of interest are divided into small cells and mobile telephones only need to communicate with a nearby cell transmitter/receiver. Each telephone cell then connects to all other cells and to telephones on the “network” using the established telephone system.

Mobile phones work because they rely on the principles of cellular radio, including relatively short range radio transmission and frequency re-use. Therefore, the effective capacity of a mobile phone network is virtually limitless as cellular density can be increased to allow access to more users, and cells can be added as the network is expanded geographically. A problem in one cell does not normally lead to failure in another cell as they can act independently. In fact, it is the contrary - since cells overlap,
Hybrid Cellular Seismic Telemetry System

if there is difficulty in one cell the adjacent cells may cope with the extra demand.

These same principles are used in a cellular seismic system although quite different transmission protocols and radio bands need to be used. Frequencies used by the cellular telecoms industry are normally around 800 MHz, 900 MHz and 1,800 MHz and the most common digital cellphone protocol is GSM, which is quite unusable for realtime seismic data transmission.

Instead, extensive use is made of existing internet and ethernet technology for data transfer. It has been estimated that these network types transmit as much data in one second as all the seismic data that has ever been recorded and there seems to be no limit to how much they can be expanded.

For the cellular seismic system to make the best advantage of the transmission media, data transfer from remote units to the central system takes place in two steps. The first step is from remote unit to a network access switch or relay called a Cell Access Node “CAN”. The second step is across cells, i.e. from CAN to CAN and on to the central system using a network of fibre optic cables.

Step one uses the high data rate digital radio technology Direct Sequence Spread Spectrum radio, operating on the 2.4GHz ISM band using the 802.11b protocol, with data encoded in TCP/IP format. Step two from CAN to CCU uses fibre optic cabling transferring data using the 802.3 protocol. The f.o cables may be laid out in networks with routing controlled by the SpanningTree Protocol. These are the main technologies leveraged to produce this new form of seismic acquisition system.

SPREAD SPECTRUM RADIO TRANSMISSION - THEORY AND APPLICATION TO THE SEISMIC METHOD

Spread spectrum is a means of modulating data using a wide bandwidth compared to the baseband information bandwidth. The signal is demodulated using a locally generated replica noise code to separate the encoded information. The particular type of spread spectrum technique used in cellular seismic acquisition is known as “direct sequence” which is already commonly used in wireless local area networks.

Spread spectrum was first used during the second world war and is very different to standard narrow band modulation. Civil and military applications today which require high data rate, low error-rate, secure and interference-immune communications tend to employ this technique and thus it is a “natural” for use in the seismic application.

The technique can be thought of as a filter which only responds to signals encoded with the noise code that matches it own. Thus, it does not respond to man-made, natural or artificial noise making it perfect for the conditions so often found in land and TZ acquisition as transmission is much less prone to interference even with signals occupying some of the same bandwidth. The DSSS technique has a very rough analogy in the correlation technique used in vibroseis. Prior to correlation, a vibroseis record looks noisy and is hard to decipher. After correlation with the appropriate pilot, reflections become more apparent.

ISM BAND - THEORY AND APPLICATION TO THE SEISMIC METHOD

The frequency band used employed is the 2.4000 - 2.4835 GHz band, wavelength ~12 cm, known as the “ISM
Band” - Industrial Scientific and Medical. This band does not require users to have a radio licence. RF power up to 1W can be used in most parts of North America, with different powers in other parts of the world. The 2.4 GHz signal is line-of-site and in free space 100 mW can transmit some kilometres. Attenuation takes places according to several factors but we take advantage of this in the seismic acquisition which specifically does not want signals to travel too far, thus allowing frequency re-use. GSM mobile phones work in a similar way. The RF power being used to transmit from cellular phone to fixed antenna array is automatically reduced to enable it just to reach the mobile phone mast and the frequency reused by other cellphone users further away.

802.11B PROTOCOL - THEORY AND APPLICATION TO THE SEISMIC METHOD

To be able to leverage on an on-going basis the technologies developed in other industries which require high capacity, low error rate digital communication, we use the IEEE 802.11b protocol, which splits the 83.5 MHz ISM bandwidth into a maximum of 13 “sub-bands” each around 20 MHz wide. As an order of magnitude, 20 MHz is 1,000 wider in bandwidth than traditional narrow bandwidth modulation. Some of the ~20 MHz bands partially overlap and some do not. Due to the DSSS modulation, overlapping bands interfere minimally with each other.

802.11b allows for a maximum of 11 Mbps data transfer rate but where there is significant interference or attenuation this data rate can be effectively reduced to as low as 1 Mbps. To be on the safe side, this cellular seismic system assumes that the user will never get more than one 1 Mbps, although experience shows this is not the case. To maintain the integrity of seismic data, the protocol comes with a built-in 32-bit Frame Check Sequence, which can detect all but 1 in 232 errors.

Other useful protocols also already exist including 802.11g working in the 2.4 GHz ISM band allowing transfer rates up to 54 Mbps. The IEEE has already announced the 802.11n which may soon be capable of 320 Mbps. We believe that the 802.11b protocol is more than sufficient for the foreseeable needs of the seismic industry, but unlike other seismic acquisition technologies, it is comforting to know that technology now being leveraged is in its infancy.

TCP/IP - THEORY AND APPLICATION TO THE SEISMIC METHOD

We now need to consider which existing technology we can “borrow” in regard to data transfer format. The format chosen was the one which is responsible for carrying more digital data round the world than any other - the TCP/IP format which stands for Transmission Control Protocol/Internet Protocol. It is robust and reliable, and is as good for handling packets of seismic data as it is for the millions of terabytes of data sent on the internet every day.

Remote units simply turn digitised geophone data into TCP/IP packets for transmission on its ISM radio, switched onto the fibre optic cable network, and when received by the central system, are turned back into a trace sequential data. Current transfer rate on the f.o cable is 100 Mbps. However, technology is already available to allow ten times this rates, i.e ten times as many seismic channels per cable in realtime.

CELLULAR SEISMIC ACQUISITION - DEPLOYMENT THEORY AND RELIABILITY THEORY

The most important characteristic of a cellular seismic system is that each remote unit can act independently of all others. This gives essential and unique advantages since overall reliability of any system is related to how many dependent parts are involved. Cable systems have parts which can be heavily dependent on each other’s functionality for the system as a whole to work. The failure of one box or cable can mean the whole system stops working, so the problem gets bigger with crew size or when working in difficult areas which is not so with a cellular seismic recorder.

Analog cable systems concentrated all the electronics in one location, which limited them to relatively few channels. Current digital telemetry “distributed systems” distribute the digitisation function to remote units around the spread giving greater channel capacity but there are still channel number limits. The next generation of seismic system must not only do away with the transfer bottleneck of the digital cable, but also must distribute, where possible, processing capability around the spread allowing the “number-crunching” capability of the total seismic system to be in direct proportion to the number of remote units.
That each remote unit can act independently is a natural and essential step in systems which cope with \(10^4 - 10^5\) channels. Reliability theory and experience tell us that sooner or later something will go wrong with a crew with 50,000 channels. But if remote units act independently of each other, and the failure of one unit does not bring down the rest of the operation, then we will probably be happy to continue acquisition with 49,996 channels. With traditional distributed systems, the failure of just one box or cable is often enough to shut down operations until it is fixed.

Additionally, even if we could envisage a digital cable vibroseis crew with 50,000 channels, who can imagine a centralised correlator-stacker able to handle 50,000 channels in zero wait time? So that each remote unit can be independent, they all have an internal processing/computer bus, local memory for shot data storage, an ISM radio system with diversity antenna and integrated Digital Signal Processing subsystem which is used for a variety of functions, including optional remote instrument tests, vibroseis correlation and/or stack, as well as data compression.

**SEISMIC CELL PROPERTIES AND DATA TRANSFER MECHANISM**

Another cellular telephony principle is the subdivision of cells into 120° wide sectors which allows more phone users to use the same cell and this is also used in the cellular seismic system. In this case, not only remote units act independently of each other, but also cells and cell segments can. This allows even greater reliability and increases data rate within the cell by a factor of three, up to 33 Mbps per cell, although again we only try to use about 10% of this realtime data transfer capacity. But it is useful to know that there is such spare capacity rather than, as with some digital cable technologies, being at the limit of capability.

To provide complete coverage of the seismic spread, it is inevitable as well as desirable that cells overlap. Cells built up or cellular telephone applications also tend to overlap and it is normally the case that a cellular telephone is able to communicate with a number of cell phone masts at the same time. The cell phone system decides which is the best permanent mast array to deal with each cell phone, and all other mast arrays “ignore” that cell phone. Similarly, as seismic remote units are deployed, they decide themselves which cell sector they will belong to.

Any interference caused by overlapping is handled by the combination of different 20MHz wide sub-bands of the ISM bandwidth, direct sequence spread spectrum and the 802.11b protocol. A side-effect of this method is that if there is ever interference between two adjacent cells, then overall data rate is reduced from its 33 Mbps maximum rather than, as with some forms of VHF modulation, a total loss of communication. Further, cellular seismic systems, as with cellular telephony, make use of the limited radio range to enable the complete re-use of frequencies without interference in non-overlapping cells.

Finally, in considering the fibre optic cabling, we should note that each CAN has the ability to be connected to four others using an f.o cable network to allow for multiple...
Hybrid Cellular Seismic Telemetry System

routes from CAN to CAN to central system which permits acquisition to continue if there is a cable problem and permits even greater data transfer capacity. Data re-routing is automatic under the "Spanning Tree Protocol".

The central system is a relatively simply device. With so much processing power distributed to field units, it does not need to worry about features like correlation. Also, unlike some systems with proprietary data transmission formats, or which have to worry about errors induced by so many interdependent units, there is relatively little house-keeping for the central system meaning it tends not to get easily hung up or fail due to line ghosting errors. With data in an industry standard format of TCP/IP the main function involved here is reformatting into SEG D or SEG Y, so the central system is easy to use and very scalable, which are certainly necessary features if we wish to see much lower cost operations, or a system with 50,000 channels being operated by one person.

EXAMPLES

The system described has clearly leveraged a number of technologies and offers many unique advantages to the land exploration industry so let us see how it copes with real life crews, the average of which in some parts of the world is already 5,000 channels and 10,000 channels is not inconceivable. Let us consider some of the practical differences between a cellular seismic system and digital cable telemetry hardware with crews this size.

Most companies are familiar with the experience of a spread working at the end of one day but having to spend some hours the next day bringing the line up again. This cost of this loss of production usually gets passed to the oil company in one form or another. These difficulties are caused primarily by cables and connector. Cellular seismic systems do not have digital cables or many contact points making it inherently more reliable and productive.

As many contractors will attest, one of the major factors affecting the cost of a crew is the weight of equipment to be carried around. Weight equals people and vehicles and HSE risk. Some of the largest oil companies in the world have financial models of crew charges which show a direct relationship between weight and cost and there are many articles in the geophysical press confirming this. It is difficult to see how weight can be cut in a cable system significantly since between 60% and 85% of the weight of a cable system is the cable system itself and it seems rather difficult to reduce this.

So how does a cellular seismic system compare? Using even some of the latest digital cable telemetry systems with 10,000 channels could require more than 60 tonnes additional weight compared to a 10^4 channel cellular system. But it is not only a problem of weight, it is also an issue of inherent reliability. Such digital cables systems could also need between 5,000 - 10,000 digital contact points all working perfectly for acquisition to be able to take place. It is also difficult to reduce the number of contact points without losing flexibility as is very well indicated in a wonderful paper written.
by Patrick Burger quite recently, which also discussed the operational costs of heavier systems.

Cables have other major costs as well. For example, if we take the figure of $50 per take-out per year being an average for digital cable repair, replacement and maintenance, and even ignoring lost production time due to digital cable/connector failure, for every 10,000 channels owned by a contractor, he can be spending more than half million dollars per annum simply on digital cables. So clearly, flexibility and reliability, as well as on-going costs are demonstrably much lower with cellular seismic acquisition, and not by just a small margin.

Another advantage of the cellular approach is that the system would easily operate under virtually any acquisition geometry. As crews get larger, or as they go into more logistically difficult areas, the problem of deployment to a fixed geometry becomes worse. A cellular seismic system, unhindered by digital cables, copes far better with a future in which we can envisage larger crews, and with the present where we want to see lower cost crews.

We may conclude from this that it is possible to consider that digital cable telemetry and RF systems which make use the VHF band, may be approaching the limit of their applicability to future and some present forms of seismic exploration, which require many more channels and much lower operations’ and hardware purchase costs. It is certainly no more possible to see how such a crew could compete with a cellular seismic operation any more than, say, a 1970’s analog cable system could compete with the latest digital cable or VHF system.

CONCLUSION

A quarter of a century has passed since the last major change in acquisition technology when the advent of digital cable telemetry helped to ensure the future of the land seismic industry and ensured that 3D acquisition became the most commonly used land survey technique. However, this market has changed out of all recognition since that time and we should not expect systems based on aging technology to provide solutions for the future or to be competitive in the present. There is no doubt that a system able to operate at significantly lower cost and able to field tens of thousands of channels is now required.

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