In today’s economic and political climate it is essential for the energy industry to maximize asset productivity. Accurate placement of the wellbore is recognized as one important key to maximizing the productivity of the well. Even more important is precise knowledge of where pay zones (and hazard zones) are located. The cost of imprecise drilling or inaccurate geologic information ranges from small losses in productivity to complete loss of the well. Even small losses in productivity can translate into unrecoverable resources worth millions of dollars. Other more sobering costs of incorrect drilling include loss of human life.

In order to avoid such losses, timely information regarding the targeted resource, the trajectory of the wellbore, and the safety and stability of the well is essential to the drilling process. However, the severity of conditions encountered in the drilling environment has largely kept the industry from entering into the age of information and connectivity. Present drilling communications technologies are analogous to sending smoke signals, which prevents much-needed information from being relayed to the top of the well with the necessary speed and completeness.

Certainly, high-speed data transmission in the drilling environment would be a key enabling technology for the energy industry. However, this technology has eluded the industry for many years. As far back as 1939, technology had been proposed to provide data from down-hole to the surface. The stumbling block in most instances was bridging the tool joints connecting segments of drill pipe together. Corrosion, shorting, and other damage to electrical connections at these hundreds of tool joints, or intrusiveness or unreliability of the data transmission system, have effectively prevented commercialization of such data transmission systems.
In 1997, a team of researchers at Novatek, Inc. in Provo, Utah initiated development of a high-speed data system that addresses the shortcomings of previous communications systems. The U.S. Department of Energy’s Strategic Center for Natural Gas, part of the National Energy Technology Laboratory (NETL), identified this initiative early on as a key strategic technology and one of the agency’s highest priority projects and provided partial funding for the project in the beginning stages. NETL involvement has since expanded to also include the National Petroleum Technology Office and has continued into the present stage of the project through a cooperative research agreement (DOE Award No. DE-FC26-01NT41229). Grant Prideco, the world’s largest drill pipe manufacturer, began working with Novatek on the data system in early 2000, and a new corporation called IntelliServ, Inc. was formed to commercialize the system.

IntelliServ’s core technology is a passive communications link that connects discrete components together. This link, known as IntelliCom™, comprises a ring-shaped transducer that can transmit data to another component without direct electrical contact. Its ring shape is ideal for communication across threaded joints, since radial orientation is irrelevant for effective communication between rings. The non-contact feature of the link allows it to be embedded and protected within drill string components and thereby avoids the pitfalls of previous electrical connector designs.

Application of IntelliCom™ links within a tool joint provides high-speed data connectivity between mated segments of drill pipe (IntelliPipe®). A uniquely designed double-shouldered tool joint geometry that is used in Grant Prideco’s line of eXtreme Torque® (XT) and Hi Torque® (HT) drill pipe provides an ideal location for the IntelliCom™ link to reside. This shoulder provides excellent protection and ideal placement of mating IntelliCom™ components.
An armored data cable running the length of the drill pipe completes the data path between IntelliCom™ links. The cable is protected inside the drill pipe and is engineered specifically to carry high-speed data with low power loss. Mechanical and electrical connection between IntelliCom™ links and the armored cable are made using a proprietary high-pressure connector that is engineered to withstand the rigors of the drilling environment.

IntelliPipe® is only one application for the IntelliCom™ technology. The technology is useful in all types of threaded drill string assemblies, including reamers, jars, stabilizers, and other subs. It can also be useful in devices that have rotating joints through which a signal must pass, including down-hole motors and a “data swivel” at the top of the string, which is used for stripping the high-speed data off the string while drilling. Again, the non-contact nature of the IntelliCom™ link is particularly useful in that the connection is easy to seal against intrusion of high-pressure fluids.

THE DOWNHOLE INTERNET

IntelliPipe® is the basic building block of a modular down-hole data transmission line, which can be used to interconnect many devices and systems that can improve drilling productivity. With this transmission line in place, information may be moved between various members of the drilling assembly much like information can be shared by several users on a network or Internet.

The IntelliServ® network includes a number of “smart” sensing or control devices, including drilling jars, motors, bits, measurement-while-drilling sensors, and other down-hole tools. These are arrayed along the length of the drillstring at strategic locations. Each of these devices can be defined as an addressable node on a downhole network and can gather data or simply relay data from a previous node to the next node. Proprietary software and hardware controls the flow of information between devices. Since every node is identifiable, events that occur at a specific node in the drill string can be correlated with a particular region of the well.
One key network device is the IntelliLink™. This device, (shown left) includes sensors and an electronics package capable of controlling flow of information and boosting data signal strength. Each IntelliLink™ is housed in a specially modified full length joint of drill pipe and includes a large through bore to allow for low fluid losses and through-access for darts, etc.

A data swivel sub at the top of the well is used to strip the transmitted signal off the drill string and send it to a drillstem data server, and from thence to locations on the drill rig floor or, in encrypted form, to the World Wide Web, making the data accessible to operations engineers and managers throughout the world. Thus, the IntelliServ® network provides enhanced real time information about the status of the well and improves connectivity between downhole devices.

The premier application of the IntelliServ® network is for seismic characterization of a reservoir during the drilling process. As a wellbore approaches a reservoir, the available accuracy of information regarding the reservoir improves dramatically if that information can be gathered down hole. High-speed data transmission makes this possible. Other applications of the IntelliServ® network include feedback and control for downhole steering assemblies, real time logging while drilling, determination of stuck point (by identification of network node), determination of downhole make up of drill joints, drillstring vibration monitoring and modeling, monitoring of gas kicks, etc.
**Benefits of the IntelliServ® Network**

**Improvements to Energy Asset Value.** The IntelliServ® network enables a better understanding and characterization of a reservoir asset. The high-speed data system increases the availability of information regarding the status of the downhole environment during the drilling process, including real-time formation characterization and downhole seismic data. This enhanced understanding allows optimized well placement, acceleration of the proving process for reserves, and an accelerated production curve. It also decreases the potential for overlooked pay zones. It is an enabling technology for more sophisticated diagnostic tools for discovering subterranean resources and more accurately assessing and ensuring the value of the asset. Furthermore, with better asset characterization while drilling, fewer wildcat wells must be drilled, minimizing cost and environmental impact.

**Improvements to Productivity.** Improved communication with the downhole drilling assembly can allow more precise drilling. Not only can the drill bit be better directed from the top of the hole to ensure proper trajectory and entry into the producing formation, but also more and timelier feedback can be available to the driller to determine where the drill should go in the first place to maximize production. Similarly, the IntelliServ® technology can improve productivity of the well by decreasing damage to the well. Increased feedback and control of the drilling process can decrease overshoot into adverse formations, which in turn can reduce contamination of the well or loss of the resource. The technology can also be used to improve and increase the use of underbalanced drilling technology, which can be used to both increase drilling speed and decrease formation damage. Currently, fluids used commonly in underbalanced drilling (foams, etc.) prevent the use of
traditional measurement while drilling (MWD) systems. With the described network, drilling fluid type is not a factor, opening the door for wider MWD use in this application; therefore, better controlled underbalanced drilling is possible. Also, better pressure profiling along the length of the drillstring (from distributed nodes in the network as described above) allows safer use and control of inherently dangerous technologies like underbalanced drilling.

**Improvements to Drilling Efficiency.** The technological advancements offered by the IntelliServ® network are expected to enable improvements in the overall drilling process that will result in faster well drilling, thereby reducing overall well costs. The time spent drilling a well is a function of several factors, including drilling speed, drilling accuracy, and rig downtime. The latter factor most notably includes time spent changing out worn equipment (drill bits, etc), mitigating well problems, and assessing well location. The IntelliServ® network offers a means for obtaining substantially more real time data so that the status of the well and well drilling tools may be better understood and the drilling process may be optimized. Real time vibration data transmitted on this system can be used to improve bit life; likewise real time position data can improve steerability. Seismic look-ahead data transmitted over the IntelliServ® network can be used to determine hazards and pinpoint pay zone location. It can also be used to optimize casing points, thereby eliminating unneeded casing strings. Enhanced kick detection offered by distributed network sensors can be used to substantially improve safety, decreasing well control costs.

**STATUS OF THE TECHNOLOGY**

**Prototype Development and Testing.**
Over a hundred full-scale joints of 5-7/8” IntelliPipe® have been manufactured and tested in a 4500 ft well at the Rocky Mountain Oilfield Testing Center near Casper, Wyoming. This test included 10 joints of heavyweight drill pipe, a short production run of 120 joints of normal weight drill pipe, and 5 IntelliLinks™. These latter joints were dispersed in the string at 1000-ft intervals to serve as data collection sites (network nodes) and to boost signal strength as needed. Communication with the drillstring was established during drilling and flushing operations through a special wired kelly and a data swivel sub at the surface. During the trip in the hole, communication was established through a simple cap that was set in the open box end of the top drill pipe.
In the test, 3000 ft of pipe were deployed in a cased section of the well, after which time the rig crew was able to successfully kick off a cement plug and drill new formation for approximately 400 ft. At that point, the drill bit entered a highly washed-out section of a previous well and fell back into the open wellbore. Further pipe was tripped in the hole until the planned 4500 depth was reached. On the trip into open hole, a few hundred feet of reaming through tight sections was required, and jars fired 4 or 5 times, offering varied loading to the system. During this test, a simple bi-directional high-speed IntelliServ® network was demonstrated with 5 IntelliLinks™ communicating at 2 Mbit/s data rate.

Other tests have been conducted in a 1,000 foot well at IntelliServ’s test facility in Provo, Utah and in a 2,000 foot test well operated by the Gas Research Institute in Catoosa Oklahoma. Full-scale tests have included multiple makeups (50-150) to full torque on several joint pairs, internal pressure loads of up to 15,000 psi and vibrational loads of up to 500 g (20 grms).

Full-scale tests have been supplemented by benchtop laboratory testing. For example, seals used in cable connections have been tested in a pressure vessel at simulated borehole conditions of 200 C and 25000 psi. Such testing continues in an effort to further improve the transmission range and drilling robustness of the system.

**FEA Modeling and Fatigue Testing.** The process of inserting a wire permanently inside a joint of drill pipe requires certain modifications to be made to the pipe. These modifications have been analyzed by predictive FEA and laboratory testing. This testing has consisted of: 1) axisymmetric FEA modeling of the standard XT57 tool joint connection (for a base line); 2) axisymmetric FEA modeling of the IntelliPipe® modified XT57 tool joint connection; 3) 3D FEA modeling of the modified internal upset geometry.
and connection; and 4) full scale cantilever beam drill pipe fatigue testing. Results of these testing programs are provided below:

1) Axisymmetric FEA of XT57 connection – the figure shows Von Mises stress for the standard XT57 connection at its maximum make-up torque (MUT) of 56,600 ft-lbs. The gradual thread root radius of 0.042”, slow taper 0.75 in/ft and double shoulder feature make the XT connection the best fatigue performing drill pipe connection offered by Grant Prideco.

![Von Mises Stress Distribution at Max. Suggested Makeup Torque of 56,600 ft-lb](image1.png)

Internal Shoulder Gap = 0.010”

2) Axisymmetric FEA of IntelliPipe® modified XT57 connection – the figure to the right shows Von Mises stress for the IntelliPipe® modified XT57 connection at a MUT of 56,600 ft-lbs. A groove is positioned in the internal secondary torque shoulder of the connection. Localized stress is present at the face of the secondary shoulder deemed not detrimental to the performance of the connection by Grant Prideco. Yielding of the pin nose at this MUT and higher has not been observed during field-testing.

![Von Mises Stress Distribution at Max. Suggested Makeup Torque of 56,600 ft-lb](image2.png)

Internal Shoulder Gap = 0.010”

3) 3D FEA modeling of the IntelliPipe® modified internal upset geometry and connection – the next figure shows 3D von mises stress of the IntelliPipe® modified internal upset geometry under severe loading conditions (759,861 lbf tension load (90% of the new tube’s tensile capacity), 30,000 psi bending stress and 7,500 psi internal pressure). Generally considered extreme and difficult analysis, IntelliServ has conducted a full three dimensional FEA analysis to illustrate the IntelliPipe® modified internal upset geometry does not produce stress concentrations that may lead to fatigue cracking in the modified region. The results of this analysis prove that
the internal modifications maintain the region of highest stress on the outside and inside diameter of the pipe rather than the localized modified internal region. This result is consistent with Grant Prideco’s standard upset product. Further evidence of this is provided in the full-scale fatigue-testing program presented below.

4) Full scale cantilever beam drill pipe fatigue testing – To support the results of the 3D FEA modeling, IntelliServ has conducted full scale cantilever beam drill pipe fatigue testing. The drill pipe tested had all IntelliPipe® modifications present. Ten test samples including box and pin ends of the drill pipe were tested to failure. To expedite the fatigue testing, large bending moments equivalent to 32 degrees per 100 ft dogleg severity and high rotational speeds have been used to generate the cyclic loads. All samples have failed from fatigue in typical locations expected of standard drill pipe designs. No samples have generated any cracking in the modified region of the internal upset geometry. These conclusions have been determined through visual examinations and further detailed analyses through the Grant Prideco Metallurgical Department.

Further Developments. Development efforts are now underway to improve the flexibility and capabilities of the IntelliServ® drilling network software and hardware. A key area of focus is integration of existing down-hole measurement and logging devices with the IntelliPipe® hardware and network system. Cooperative efforts with major tool manufacturers are presently underway. Other completely new tools and applications for the network are also being developed.

A second key area of present focus is improving the passive transmission range of the system. As mentioned above, the present system has demonstrated transmission of 1000 ft. prior to needing a boost in signal level. Improvements to transmission line efficiency and electronic module sensitivity are expected to bring as much as a five-fold increase in this passive range. Work to bring about these improvements has already begun.
A third area of focus is to extend the transmission line to other drillstring elements including jars, drill collars, and miscellaneous subs. Work in each of these areas is presently progressing. As a matter of particular interest, IntelliServ is working closely with a major manufacturer of drilling jars, and a design for a wired jar is expected to be tested during 2\textsuperscript{nd} quarter of 2003.

Finally, further work is needed to increase the high pressure and high temperature capabilities of the IntelliCom\textsuperscript{TM} components and the network electronics, so that these components may be used in the deepest wells and under the most severe drilling conditions.

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**SCHEDULE**

**Milestones.** Commercial introduction of the IntelliServ\textsuperscript{®} system is anticipated during 4\textsuperscript{th} quarter 2003. In order to prepare the technology adequately for commercialization, several milestones have been set, including:

- Demonstration of initial third party tool interface – Q1’03
- Demonstration of wired jar and drill collars – Q2’03
- Completion of deep well robustness tests – Q2’03
- Testing of full drill string network – Q3’03
- Field demonstrations and initial commercial applications – Q4’03

A major effort and a major key to all of this work is field qualification of the system. IntelliServ is presently seeking opportunities to field test the data transmission system in low risk applications. Such testing, though not without risk, is seen to be fairly benign to normal drilling operations since the test will largely consist of handling drill pipe. System failures encountered in the testing, if any, are expected to have minimal impact on the drilling process, and can be corrected during normal tripping of the string. Field testing of the system can commence during late 1\textsuperscript{st} quarter 2003 and is expected to continue throughout the year.

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**COMMERCIALIZATION EFFORTS**

Novatek and Grant Prideco have formed a company named IntelliServ, Inc., which will be the primary sales and service entity for IntelliPipe\textsuperscript{®} and other drill string elements such as IntelliLinks\textsuperscript{TM}, “data swivels,” drillstem and web servers, and subs that interface with 3\textsuperscript{rd} party measurement, logging, and control tools.
A primary function of IntelliServ will be to modify and assemble drill pipe and other drillstem elements. In preparation for this function, specialized machinery capable of production-volume pipe modification has been built. Facilities have been acquired with sufficient laboratory and warehouse space to handle the remaining development work, as well as initial commercialization efforts. In addition, substantial land has been purchased, which offers suitable accommodation for a full-scale production and servicing plants and shipping facilities.

CONCLUSION

The IntelliServ® network is a key enabling technology for the energy industry, which will undoubtedly result in revolutionary improvements in the accessibility and commerciability of energy resources. Certainly, bringing “information age” technology to the drilling environment has long been an industry priority. IntelliServ is committed to bringing this industry dream to fruition.

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