Performance Assessment of Indian Meteorological Ocean Buoys With INSAT Telemetry

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Abstract
This paper assesses the reliability of data reception of the offshore moored Indian meteorological buoys equipped with INSAT telemetry and used for monitoring the Indian seas. Based on 11,952 data transmissions spanning 4.2 buoy-years, the data reception performance of the INSAT-based telemetry system is found to be 98.74%, with a corresponding data “mean time to failure” (MTTF) of 51 h. It is also identified that the moored buoy telemetry hardware conforms to an IEC 61508 Safety Integrity Level 4. The identified reliability results serve as a guideline for offshore system designers using INSAT telemetry. Meteorological data buoys with INSAT telemetry shall provide an opportunity for collecting extensive and cost-effective oceanographic data, which are used for improving the effectiveness of the Indian Ocean monitoring programs and for cost-effective integrity management of critical systems used for tsunami early warnings.

Keywords: moored surface buoy, INSAT telemetry, reliability

Introduction
Collecting extensive spatiotemporal meteorological and oceanographic information from offshore moored surface buoys (MSBs) is essential for a better understanding of ocean dynamics and atmosphere-ocean interactions and to improve the weather and ocean state forecast (McPhaden et al., 1998; Venkatesan, Arul Muthiah, et al., 2013; Venkatesan et al., 2016). This requires cost-effective and reliable telemetry systems for transmitting the data from the MSBs to the shore centers. The Bay of Bengal (BoB) and the Arabian Sea basins are locations where large portions of the South Asian coast generated cyclones are formed, and India has been a victim to more than 12 severe cyclones in the past decade, including the Category 4 Cyclone Phailin in October 2013 and Cyclone Hud Hud in October 2014 (IMD-Hudhud, 2014; SAARC, 2008; Venkatesan et al., 2014). The Ocean Observation Systems (OOS) group of the National Institute of Ocean Technology (NIOT), with a mandate to develop, operate, and maintain moored buoy observational and related telecommunication networks in the Indian waters, have carried out nearly 750 moored buoy deployments for collecting meteorological, water surface and subsurface parameters, and tsunami water-level data, ranging from coastal waters to deep oceans (Venkatesan, Arul Muthiah, et al., 2013). The MSB, which have recorded extreme weather conditions, including 19 cyclones and six tsunami events from 1997 to 2015, have collected more than 5 million data sets (Venkatesan, Arul Muthiah, et al., 2013; Venkatesan et al., 2016). The coverage of the MSBs ranges from 63°E to 94°E and 6°N to 20°N, and their locations are shown in Figure 1. The MSB is composed of three families: the meteorological ocean buoys for measuring and telemeasuring the meteorological and sea surface parameters; the Ocean Moored Buoy Network in the Indian Ocean (OMNI) for measuring and telemeasuring the meteorological, surface, and subsurface profiles up to 500-m water depths; and the Indian Tsunami Buoy System (ITBS) for detecting and reporting the water-level changes during tsunamis (Venkatesan, Ramasundaram, et al., 2015; Venkatesan, Shamji, et al., 2013). The 24 x 7 manned Mission Control Center (MCC) at the NIOT receives data transmitted from the MSBs, and the customized Advanced Data Reception and Analysis System (ADDRESS) software enables data analysis and dissemination of the data to decision makers (Venkatesan, Ramasundaram, et al., 2015). NIOT uses INMARSAT telemetry approved by the Government of India for real-time data telemetry for all MSBs with two-way communications. The second section describes the satellite-based...
telemetry systems used for ocean observations, the third section details the INSAT telemetry used for MSBs, and the fourth section analyzes the reliability of data reception.

**Satellite Telemetry Systems for Ocean Observations**

Satellite-based telemetry offers reliable real-time transmission of data from offshore MSBs. Globally moored buoy operators use the services of satellites, such as the IRIDIUM, Advanced Research and Global Communication Satellite (ARGO), International Maritime Satellite (INMARSAT), and Indian National Satellite (INSAT) for real-time data transmission from OOS (McPhaden et al., 1998; Venkatesan, Arul Muthiah, et al., 2013). The IRIDIUM satellite network is composed of a constellation of 66 cross-linked low-Earth-orbit (LEO) satellites using L-band frequencies with frequency division multiple access for data downlink. The satellite positioned at LEO at approximately 760 km features global coverage, low transmission power, high data rates, low latency, and two-way communication capability. However, the IRIDIUM-based communication service is not authorized for use in India and China (Leopold & Miller, 1993). ARGO uses polar orbiting satellites to provide global coverage, and it is used for transmitting unidirectional messages of sizes up to 32 bytes, but it lacks the data acknowledgement facility (Schmid et al., 2006). The INMARSAT-based satellite transmission is the most attractive option for deep-ocean MSBs for reliable real-time data telemetry. The INMARSAT-C, which has 10 satellites positioned at geostationary orbit, provides two-way communication, data storage, and forward facility and features data acknowledgment between the satellite and the transmitter for every data transmission. The service, which offers communication at speeds between 600 bps and 492 kbps, is reliable and secure and is charged approximately US$ 0.15 for transmitting 32 bytes of data from offshore MSBs (Graff et al., 2006). An electrical power of 23 W is required for the data transmission. The INSAT system, initiated in the 1980s, is one of the largest domestic communication satellite systems in the Asia-Pacific region. It is a multipurpose geostationary satellite providing meteorological, telecommunication, and broadcast services; weather forecasting; disaster warning; and search and rescue. Presently, more than 11 satellites are in operation such as INSAT-4CB, INSAT-4B, INSAT-4A, EDUSAT-5, INSAT-3E, GSAT-2, INSAT-3A, KALPANA-1, INSAT-3C, INSAT-3B, and INSAT-2E. INSAT telemetry has revolutionized satellite telemetry, and INSAT-3A and INSAT-3C transponders are being used for data telemetry applications (Zacharia et al., 2014).

**INSAT Telemetry for Indian Moored Buoy System**

For the first time, INSAT telemetry is used for telemetering offshore MSB collected data to the Indian National Center for Ocean Information Services (INCOIS) in Hyderabad and MCC at NIOT. Considering the importance of ocean monitoring using MSBs, INSAT telemetry service is provided free of cost by the Department of Space, Government of India. Thus, by using INSAT telemetry, significant reduction (>96%) is obtained in the air time charges compared with INMARSAT telemetry.

**MSB Transmitter**

A block diagram of the MSB located transmitter section is shown in Figure 2.
The section consists of a GPS receiver, message generator, binary phase-shift keying (BPSK) modulator, frequency synthesizer, power amplifier, and a built-in omnidirectional antenna.

The MSB Data Acquisition System (DAS) processor is customized to have a low power consumption of 1 W and is interfaced with the transmitter, using a serial data interface programmed to exchange data at a data rate of 9,600 bps. The transmitter also has a built-in GPS receiver to acquire the real-time position of the MSB. The transmitter, DAS, and GPS are powered from the onboard energy storage system, which comprises solar-powered lead-acid batteries backed with primary LiSioCl2 battery banks, configured to meet a safety reliability (SR) of the safety integrity level of 4 (SIL4) (Venkatesan, Vedachalam, Arul Muthiah, et al., 2015). The DAS obtains the position, date, and time information from the GPS unit; packs it along with the oceanographic sensor logged data; and dispatches it to the message generator, which incorporates the identity of the MSB. Message generation is based on the BPSK technique, using a frequency synthesizer, and the generated signal is amplified in three stages using a power amplifier with an output gain of 46 dB at 10-W maximum power. The output of the power amplifier is transmitted to the satellite through the MSB-located antenna, which transmits 55 bytes of data at 300 bps.

**Shore Receiver Stations**

Two INSAT receiver hubs are installed for receiving MSB transmitted data, one at MCC-NIOT and the other at INCOIS. The INSAT Mobile Satellite Services (MSS) hub at INCOIS receives data from the offshore and coastal MSBS and also from tide gauges and automatic weather stations. The Data Relay Transponder (DRT) terminal operates at ultra high frequency (407 MHz) and transmits messages of up to 110 bytes at 300 bps. The block diagram of the NIOT-MCC–located receiving station is shown in Figure 3.

The INSAT DRT hub is established at NIOT-MCC for exclusively receiving real-time data transmitted from the OMNI buoys. The satellite transponder receives the signal from the MSB transmitter, and the local oscillator modulates the received data and transmits it with a downlink frequency of 4.5 GHz in C-band. The receiving stations house a 3.8-m parabolic antenna to receive the signal through a low-noise amplifier, which amplifies the received low-level signals. The output of the amplifier is converted from radio frequency to intermediate frequency range (from 70 MHz to 9 kHz) with double down conversion, with a gain of 31 dB. The demodulator with the decoder accepts 9-kHz signals at a level of ~20 dBm (1.3 Vpp), which are digitized and fed to a demodulator that demodulates the BPSK-modulated signal into the ASCII format. The ASCII formatted data are sent by electronic mail, using the application software that extracts the data, which are received in the ASCII format.

**Evaluating the Operation and Data Reception Performance Power Consumption**

The INSAT-based telemetry system is installed in an MSB, and the power consumption pattern of the DAS and telemetry systems logged is shown in Table 1. The incorporated power management system maintains the INSAT modem in the off-state during the idle period and by switching it during each transmission cycle. The feature of switching it during transmission helps in achieving 29% reduction in the energy consumption of the MSB. The power consumption performance of the developed system is found to be around 1.78 Ah for a day involving eight transmissions.

**Performance of Buoy With INSAT Telemetry**

The developed INSAT-based telemetry system is installed in five meteorological MSBs for evaluating the quality of data reception. The MSBs were instrumented with air pressure, air temperature, wind speed, wind direction, relative humidity, wave, water current speed, and current direction and sea surface temperature sensors. The locations of the MSBs are shown...
in Figure 4. The figure also shows the deployed photograph of the MSB CALVAL off Agatti in the BoB at 10°33.53′N/72°15.36′E where the water depth is 2,000 m (Shukla et al., 2013).

During the 1-year evaluation period, from February 2014 to January 2015, the MSBs were set to transmit the acquired data every 3 h. As the INSAT telemetry does not have a data acknowledgment facility, each transmission is done thrice, taking into consideration the limitations in onboard energy storage. It is found that the consumption was about 2.3 kWh/day, which is 22% more than the power consumed by the MSBs operating with INMARSAT telemetry. The INSAT telemetry link involves data transmission from the MSB to the receiving station at INCOIS through INSAT and retransmission of the received data through the VSAT terminal to the NIOT-MCC. Figure 5 shows the meteorological parameters collected by the MSB DAS at various sample periods depending on the sensors at 3-h regular intervals, and the averaged data are transmitted through INSAT telemetry from the CALVAL MSB.

**TABLE 1**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Data</th>
<th>Current Consumption in mA at 12VDC</th>
<th>Power Line Delay (s)</th>
<th>No. of samples</th>
<th>Sample Interval (s)</th>
<th>Ah/Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Acquisition</td>
<td>175 Active 25 Idle</td>
<td>0</td>
<td>–</td>
<td>3600</td>
<td>0.180</td>
</tr>
<tr>
<td>2</td>
<td>Transmission</td>
<td>1,600 Active 0 Idle</td>
<td>60</td>
<td>1</td>
<td>30</td>
<td>0.040</td>
</tr>
<tr>
<td>3</td>
<td>Idle</td>
<td>40 Active 0 Idle</td>
<td>0</td>
<td>1</td>
<td>150</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Total power consumption/transmission: 0.222

Total Ah/day (eight transmissions): 1.78

**FIGURE 4**

Location of the MSBs and CALVAL site (Shukla et al., 2013).

The data “mean time to failure” (MTTF) is 150 h, which corresponds to one failure for every 51 transmissions. Postdemonstration analysis is done at the NIOT-MCC on all the MSBs that were programmed to store the transmitted parameters in their internal database along with the timestamp. The analysis revealed that the MSB has transmitted all the data, specifically those that were not received at the MCC. The 233 (1.954%) of 11,952 data sets of the data transmitted by the MSB were not received at the MCC; this could be attributed to a combination of factors including the weather, MSB-INSAT data link performance, and system availability at MCC and INCOIS. In case a data acknowledge feature had been available, the MSB might have retransmitted the data to the INSAT until a successful transmission is achieved.

**Data Reception Performance**

Table 2 shows the quality of data reception at NIOT-MCC, based on the collected data sets during the evaluation period involving 4.2 buoy-years.

From the received data, it can be seen that the average data reception performance is 98.046%. Statistical analysis is done, and it is found that the data “mean time to failure” (MTTF) is 150 h, which corresponds to one failure for every 51 transmissions. Postdemonstration analysis is done at the NIOT-MCC on all the MSBs that were programmed to store the transmitted parameters in their internal database along with the timestamp. The analysis revealed that the MSB has transmitted all the data, specifically those that were not received at the MCC. The 233 (1.954%) of 11,952 data sets of the data transmitted by the MSB were not received at the MCC; this could be attributed to a combination of factors including the weather, MSB-INSAT data link performance, and system availability at MCC and INCOIS. In case a data acknowledge feature had been available, the MSB might have retransmitted the data to the INSAT until a successful transmission is achieved.

**Reliability Analysis**

Reliability is the ability of the system to perform its intended functions under defined conditions for a specific period. IEC 61508 is a standard for implementing instrumented safety systems using the principles of SIL concepts (IEC 61508, 2000; IEEE Standard, 1997; Vedachalam, 2013; Vedachalam et al., 2014). Telemetry
systems need to perform their intended operations on demand. The probability of failure (PoF) on demand (PFD) is defined by SIL. SIL has four levels, 1–4. Table 3 describes the various SIL levels, with the corresponding PFD.

Based on the achieved performance, with one failure for every 51 transmissions and an MTTR of 1 h, a reliability analysis is done using the GRIF reliability analysis software (Vedachalam, 2013) using dormant law, which has a provision to incorporate failure rate, MTTR, and delay. The result of the analysis is shown in Figure 6.

It is found that the PFD for the INSAT-based telemetry system is $8.5187 \times 10^{-4}$. From Table 3, it can be seen that its performance complies with IEC 61508 SIL3 (IEC 61508, 2000). As the MSB has transmitted all the 11,952 data packets without any failure, the telemetry hardware is found to comply with SIL4.

**Discussion and Conclusion**

The reliability of the data reception using INSAT telemetry is evaluated in five meteorological moored ocean buoys accumulated over 4.5 buoy-years and involving 11,952 transmissions. The following are the major findings of the study:

a. The MSB INSAT telemetry hardware systems are found to comply with IEC 61508 SIL4—the highest level of SR.

b. The INSAT telemetry with a data reception performance of 98.046% with an MTTR of 1 h complies with SIL3. The data unavailability could be due to a combination of factors including the weather, MSB-INSAT data link performance, and shore system availability.

c. With message acknowledgment feature incorporated and other improved features, INSAT could attain SIL4 level of reliability.

d. The SIL3-rated INSAT telemetry link could be used for implementing cost-effective integrity management of other critical offshore observation systems/networks.

<table>
<thead>
<tr>
<th>Buoy ID</th>
<th>Location</th>
<th>Data Packets Transmitted</th>
<th>% of Received Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB01</td>
<td>11°35.36N/92°35.82E</td>
<td>2,920</td>
<td>99.52</td>
</tr>
<tr>
<td>CB02</td>
<td>10°52.92N/72°13.13E</td>
<td>2,440</td>
<td>99.06</td>
</tr>
<tr>
<td>CB04</td>
<td>15°23.92N/73°45.07E</td>
<td>1,512</td>
<td>97.82</td>
</tr>
<tr>
<td>CB05</td>
<td>14°16.92N/80°12.23E</td>
<td>2,160</td>
<td>96.3</td>
</tr>
<tr>
<td>CALVAL</td>
<td>10°33.85N/72°13.25E</td>
<td>2,920</td>
<td>97.53</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>11,952</td>
<td>98.046</td>
</tr>
</tbody>
</table>

**TABLE 2**

Quality details of data collected from MSBs.

<table>
<thead>
<tr>
<th>Buoy ID</th>
<th>Location</th>
<th>PFD (per Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$10^{-1}$ to $10^0$</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$10^0$ to $10^1$</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$10^1$ to $10^2$</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$10^2$ to $10^3$</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$10^3$ to $10^4$</td>
<td></td>
</tr>
</tbody>
</table>

Vedachalam, 2013; Vedachalam et al., 2014.
e. The cost-effective INSAT telemetry could be used for collecting increased spatiotemporal meteorological and oceanographic data from the Indian Oceans, which could be used for modeling weather and climate patterns.

The use of INSAT in realizing the cost-effective SIL4 integrity management of time-critical offshore observation systems was demonstrated by installing the INSAT telemetry system along with the operating INMARSAT telemetry in one of the prototype buoys in the ITBS located at 06°20.09′N/88°35.06′E (Sundar et al., 2015). Based on the achieved level of reliability and to achieve SIL4 compliance, the buoys in the ITBS network are set to communicate their health status (proof test interval) to the NIOT-MCC every 3 h (Venkatesan, Vedachalam, Sundar, et al., 2015). As the INSAT telemetry link was programmed to transmit the healthiness of the buoy telemetry system (including INMARSAT subsystems) every 1 h to the NIOT-MCC, the proof test interval of the INMARSAT was increased to 24 h. This prototype hybrid telemetry system was proved to be successful by means of detecting a sea level change during an underwater earthquake that had its epicenter at the location of 07°38.63′N/94°17.04′E. Thus INSAT telemetry has resulted in reducing INMARSAT air time charges by 96% in the prototype system. The methodology could be applied for other MSBs involved in cyclone monitoring applications (Chinthalu et al., 2002). The data reception performance of the system with INSAT telemetry gives confidence on the system’s reliable support to the Indian Ocean monitoring program, for collecting increased amounts of quality and cost-effective meteorological and oceanographic data.

Acknowledgment

We thank the Ministry of Earth Sciences, Government of India, for funding this project, and the members of the National Expert Committee for evolving this program. We are grateful to Dr. Jeyamani, Advisor, and staff of INCOIS Hyderabad for the establishment of the INSAT reception setup at INCOIS. We are grateful to the Directors of NCAOR, Goa, and INCOIS, Hyderabad, for providing all the facilities and logistic support. We also thank the staff of the OOS group, Vessel Management Cell of the NIOT, and the ship staff for their excellent help and support onboard.

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