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COMMUNICATIONS CHALLENGES IN THE ARCTIC: OIL AND GAS OPERATIONS PERSPECTIVE

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ABSTRACT

Challenges when operating offshore systems in the Arctic were addressed and analyzed from general data communications systems to distress communications systems. Two methodologies were developed with tools for estimating: a) Rainfall rate in the worst case as well as the degradation due to the highest rainfall rate to link budget of typical satellite links; b) Performance of any service at a given geographical area or location. The evaluations were for diversified inputs such as geographical locations were ranging from further south to high North; the most typical satellite communications systems in the region; and an abundant list of services dedicated to offshore Oil and Gas industry, the paper has provided a wide range list of results and recommendations when analyzing services performances from low to high latitudes and west to east longitudes. An important conclusion was that voice-relevant services were not working fine for both Inmarsat and VSAT from the latitude of 73.5 degree North regardless of the bandwidth of the satellite when assuming the deadline for these voice packets was one second. These services can be partially of fully satisfied by Inmarsat or VSAT depends on the bandwidth provided if working below that latitude. For file transfer services, it is possible to guarantee a certain satisfactory ratio at high latitude provided a compensation for bandwidth. The paper[1] also provides other numerical results in regarding of link compensation that can be used for new satellite link purpose.

INTRODUCTION

While it is considered a distinct region, the Arctic can be defined in a number of different ways. An easy way is to mark the border by 66°33’ North latitude (*the Arctic Circle*), which is also the boundary of the *land of the midnight sun*. Above this latitude, the sun remains above the horizon all day for a period during summer and stays below the horizon all day for a period during winter. These phenomena are called *polar day* and *polar night*. The Arctic covers an enormous region of around 30 million square kilometers The Arctic Ocean, which surrounds the North Pole and is largely frozen for much of the year, occupies about one-third of the region. All of which are abundant in oil, natural gas and marine life [1]. It consists of the northernmost territories of the eight Arctic states: Russia, Canada, Greenland (*Denmark*), the United States (*Alaska*), Iceland, Norway, Sweden, and Finland. Due to the cold temperatures, a constant ice cap covers the Arctic Ocean. Since the 1970s, the area covered by year-round ice has decreased significantly. This had led to most researchers believing that the ocean will be completely free of ice in the summer sometime between 2030 and 2070 [2]. The harsh climate in the Arctic has made operations in the area challenging for example to merchant ships, fishing vessels, cruise ships and operations in oil and gas industry. As a demand, in November 2014, the IMO adopted the International Code for Ships Operating in Polar Waters [3] and it was enforced from 2017 [4]. New technological solutions that help coping with the harsh environment have arrived, but some problems remain unsolved, for example the problems related to communications.

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[1] SINTEF Ocean (formerly MARINTEK) started from January 1st 2017 through an internal merger in the SINTEF Group

During the next 10 to 15 years, there will definitely be an increase in activity related to energy exploration and production in the Arctic where oil and gas industry is one of the majors. Other stakeholders such as shipping, fishing, tourism and scientific research activities will also increased in the area. Consequently, the demand for reliable voice and data communication has increased, but the technologies have not quite been able to keep up with the increased market demand. New solutions are required to ensure safe passages for ships in the Arctic region; luckily, they are already on their way [5]. For facilitating any kind of vessels moving towards the Arctic, the most importance is to ensure a reliable communications system for daily operations and in the case of emergency. The International Maritime Organization (IMO) has the legislative control over the rules and regulations of the Global Maritime Distress and Safety System (GMDSS) using Inmarsat-C system [6]. Even though GMDSS is considered a global system, it has limitations when sailing beyond 75°north (and 75°south) mainly because of the lack of coverage in geostationary satellite orbit. Ships currently have to carry multiple GMDSS-systems on board, some of them using dated technology and equipment. When sailing above 75°north, ships might experience lack of reliable connectivity for several hours or even days [2]. Sailing in these areas can then be considered quite risky, as there can be periods when communication between the ship and shore is not possible [7].

At the present, the only obligatory of distress communications set by IMO in the Arctic area is the use of HF-radio. However doing communications in this band is sensitive to interference from solar activity and is known as a potential problem in the Arctic regions. For vessels, sailing in these Arctic waters there is also a possibility for deploying an *EIRP* (Emergency Position-Indicating Radio Beacon) which sends an alarm containing the vessels position. On top of the regulated minimum safety communication, modern ships and oil platforms alike rely on broadband Internet connectivity for maximal operational performance. Not all of the companies operating in the Arctic region take well enough precautions and understand the limitations and challenges in communication that the region offers [5]. For example, search and rescue operations can be extremely challenging because of the long distances, harsh weather and possible problems with communications. The Norwegian *SARiNOR* project (Search and Rescue in the High North) is a cooperation between different companies with a goal to find the best and most effective ways for search and rescue operations that happens in the Arctic areas [8]. Inmarsat-C has had a monopoly position in the *GMDSS* system for several years now. There are other satellite communication service providers in the market such as Iridium, Telenor and Thuraya, but none of these has yet been allowed to be used for official GMDSS purposes.

This paper focuses on defining general data communications services, demands and its challenges when doing data communications in the Arctic for oil and gas industry. The evaluations are mainly for daily services on platforms, specifically the data demands between (shore) control room and O&G platform as well as services for crew on board and operating systems. The services also include voice communications to shore in emergency case, and of course it could be used in distress cases on top of regulated GMDSS systems. Oil and gas industry was selected for evaluations because of its high bandwidth demand and delay sensitive services. In addition, this industry has also shown an intention of clarifying more about communications infrastructure and service performances in the High North regions when implementing O&G services. The list of services and bandwidth demands will be varying according to the specific phase of oil and gas production cycle. This cycle starts from Exploration phase to Appraisal, Development, Production and ends at Decommissioning phase (See Fig. 1). Normally, the communications demand starts to increase from the starting phase with data communications which mainly use satellite communications systems. The highest demand will be happened at the beginning of development phase when almost of the services in Table 1 are demanded. Nowadays, the offshore system can be controlled and managed with the use of Integrated Operation (IO) system. For example, onboard systems could be remotely controlled from a room on shore. This IO usually needs online monitoring and controlling systems, so it significantly increase bandwidth demand. Other services such as for crew and staff on board entertainments also consume lots of bandwidth. At this phase, existing platforms or rigs usually have a fiber optical cable connecting to shore, and its provided bandwidth is high, starting from 100Mbps to several Gbps. With this fiber optic, it can provide all broadband services to shore and crew on board as well as to supporting vessels (usually these vessels have a broadband connection with the platform/rig).

The demand of data communications slightly reduces at the end of Production phase and sharply reduces at Decommissioning phase. At this ending phase, permanent communications infrastructures (e.g. optical fiber cable system) will be removed and satellite communications is the main solution for communications between offshore installation/vessels and shore.

For the remained part of paper, the coming sections are introduced with this order: demand of data communications in O&G; external degradation factors on radio link; link budget for satellite link with normal and worst case of rain at high latitudes; methodology for service performance evaluations; evaluation scenarios for simulations; results and conclusion.

DEMAND OF DATA COMMUNICATIONS IN O&G SECTOR

Full list of services

From direct interviews with end users in the field of O&G in Norway and references from other projects working for high North regions [9], following Table 1 provides a full list of the

TABLE 1. FULL LIST OF SERVICES

Service Name
Emergency call to Shore
Telemedicine (TeleMed)-VideoTelephony
Telemedicine - Health information
Telemedicine - Images
Telemedicine -Voice communications
Weather data distribution
Helideck motion information
Entertainment
Seismic data
Logistics
Operation maintenance
Drilling report
Video conferencing
Contractual related tasks
Sensor data
Telemetry from offshore
Data (onshore to offshore)
Telemetry from onshore (commands)
Still images (CCTV)

most important services for O&G offshore.

Definition of service parameters

Each service in the Table 1 have been addressed with these parameters:

1. Name of service;
2. Type or format of data: It could be a specific format of data (e.g. IP based voice communications, MPEG for images, H232 for video conferencing and so on). In general, this field can be *File* or *Streaming* or combined *File*/*Streaming*;
3. File size or Frame size in kilo-bytes: It varies depends on the service type or it could come from assumptions;
4. Duration in second: The period of time the service will be used (for sending a data packet, file or frame). For streaming service, it is assumed that transmission is carried out for each frame size.

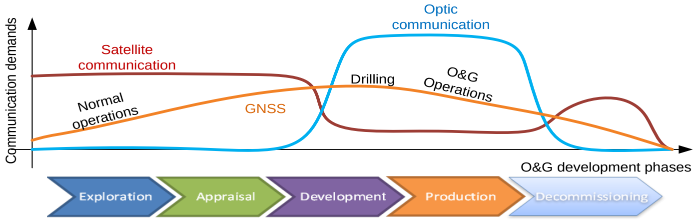


FIGURE 1. The phases in an oil and gas production cycle

5. Bandwidth per user in kilo-bit-per-second: The minimum bandwidth required to use the service. This value is usually referred from NORSOK standards or ITU-R relevant standards or assumptions;
6. Deadline in second: Is the maximum of allowed delay for the service. This deadline is usually taken from ITU-R standards, NORSOK standards [10] or assumption;
7. Usage of the service: It could be one of these two cases:
   (a) Repeatedly use the service after a duration of time called interval. If so, *Every* is presented and the interval (in seconds) is shown at the column on the right side;
   (b) The service is limited used only at a specific number of times. This case, *Total* is presented and the total number of times the service is used per day is showed to the column on the right side;
8. Priority: Is the priority of the service to utilize the channel. It could be any of these values: 5 (*High*), 4 (*Medium*), 3 (*Low*) or 0 (*Best Effort*). This priority level will directly affect to the right to utilize and yield the channel. This feature will be explained in details in the methodology;
9. Number of users: The number of stations or end-users need to use this service. The bandwidth required for a service will therefore be linear with the number of users;

For the purpose of evaluating only typical services when communicating over existing satellite links in the high North regions, a short-list of services were chosen in column #1 of Table 2. The following columns show the values for the defined parameters for each service. The values of these parameters were taken from these sources: NORSOK T-001, T-003 and T100; ITU-R documents. Some of the parameters were assumed for the evaluations. All of these values are easy to change when needed and the evaluations will be varied accordingly.

EXTERNAL DEGRADATION FACTORS ON RADIO LINK

At low frequency spectrum such as HF/MF, VHF and even L band, radio link is vulnerable with the solar activity in the high

TABLE 2. Parameters of the services used in evaluations

Service	Format	Size	Tx Duration	BW/user	Deadline	Interval	Number	Priority	Users
Emergent call to shore	IP voice	0,05	60	128	1	Every	1800	5	1
TeleMed-Video	H323	0,05	180	614	1	Total	15	4	1
TeleMed-Health Info	File	64	2	256	5	Every	60	4	1
TeleMed-Images	512	4	1024	15	Every	300	4	1	
TeleMed-Voices	IP voice	0,05	30	128	1	Every	120	4	1
Weather data	File	500	8	512	60	Every	3600	4	1
Seismic data	File	10240	80	1024	300	Every	173	3	1
Video conferencing	H323	0,05	60	307	2	Every	1800	3	2
Data from sensors	File	150	5	256	30	Every	600	4	1
Telemetry with offshore	File	50	3	128	10	Every	300	4	1
Inputs from onshore	File	50	3	128	10	Every	1800	4	1
Commands to offshore	File	50	3	128	10	Every	1800	4	1

North regions due to strong magnetic fields. At higher frequency bands such as Ku and Ka bands which are popularly used in satellite communications systems (e.g. VSAT and Inmarsat), the main external degradation factors could be addressed are rain, atmosphere gases, snow and ice. In design phase, it is necessary to compensate these losses for link budget in order to ensure an acceptable level of link quality (see these factors in Fig. 2). This is also the way that satellite providers used to estimate the EIRP (Equivalent Isotropic Radiation Power) map of a specific satellite. Besides these factors from transmission medium, physical elevation angle (the angle between satellite to land based user and the horizon) also contributes to the degradation level of the link and service. The lower this angle the larger degradation on the link. In the scope of this paper, only the effect caused by rain was evaluated because of its majority in link degradation comparing to the ones from snow and ice. Normally, rainfall rate can be obtained by using the method recommended by *ITU-R* (International Telecommunications Union-Radio), and assumed the rainfall is *IRR*. However, *IRR* is actually the average of the rainfall rate in a relative large area due to a low resolution of rainfall map. Therefore, there is a need to estimate the maximum rainfall rate, assumed to be *MRR*, that is directly processed and extracted from *ECMWF* (European Countries Medium Range Weather Forecast). These values will be given to the estimation for a comparison of the link budgets in these two situations (of rainfall values).

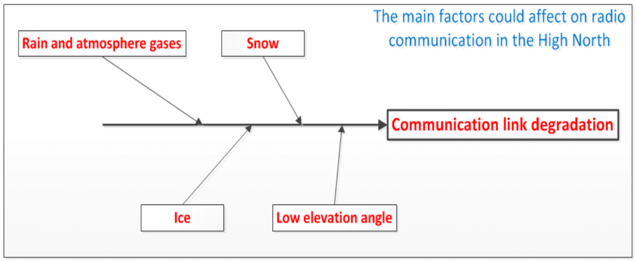


FIGURE 2. Potential degradation factors to radio links

LINK BUDGET WITH IRR and MRR AT HIGH LATITUDES

This section presents a comparison for the satellite link budget when applying rainfall rates for the two cases, equal to *IRR* or *MRR*, with a diagram in Fig. 3. The process to achieve *MRR* and *IRR* will be explained in details in the next section. Briefly, *IRR* is obtained by using a built in Library called *CNES Propa.DLL*; *MRR* however needs other steps to process and extract data from large file in *NetCDF* type, source is from *ECMWF*.

Rain estimation: IRR and MRR

Before comparing the link budget at *IRR* and *MRR*, these rain rates are extracted and compared at the same longitude and

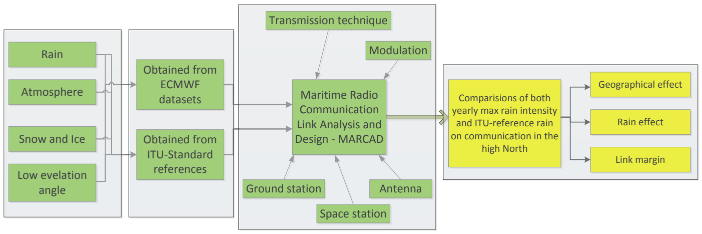


FIGURE 3. Processes for estimating rainfall values (IRR, MRR)

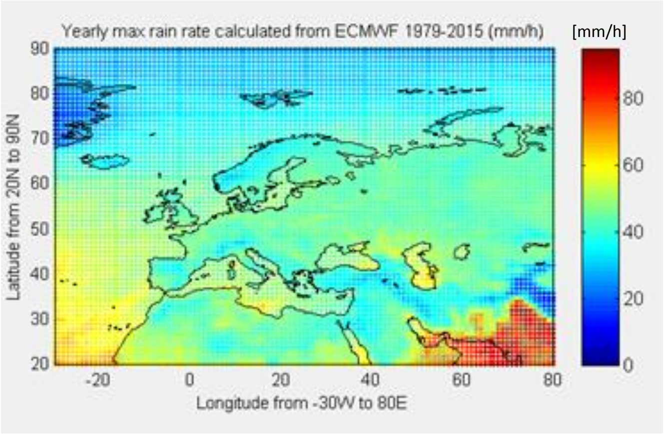


FIGURE 4. Maximum rainfall rate (*MRR*)

latitude. In order to make the difference between *IRR* and *MRR* distinguishable, Fig. 5 shows the rainfall rates in mm/h for *IRR* and Fig. 4 shows rainfall rates for *MRR* when plotting on the same coordinates.

These values are plotted in a geographical region 20°W20°N-80°E90°N. This region fully covers Norway's territory and the Arctic sea areas above Norway; it can however easily extend to any direction upon the user request. The most noticeable colors from these plots are dark blue, light blue and yellow. The dark blue color represents for the rain values 0-20 mm/h (the darker blue the lower rain rate); the light blue one is for the rain rates between 25-35 mm/h; and the yellow one is for higher rainfall rates between 50 and 60 mm/h. The area painted red has high rainfall rate which can be 80-90 mm/h. The red area is visible somewhere in *MRR* map (Left) but it does not exist in high latitudes regions.

This difference is more contrast when looking at the latitudes starting from the highest point of Norwegian mainland for instance at 72°N. For example, *MRR* in Svalbard island could be up to 40-50 mm/h and is significantly higher than *IRR* in the same area, which is only around 30 mm/h. The difference between *MRR* and *IRR* in this example can be between 10 and 20 mm/h.

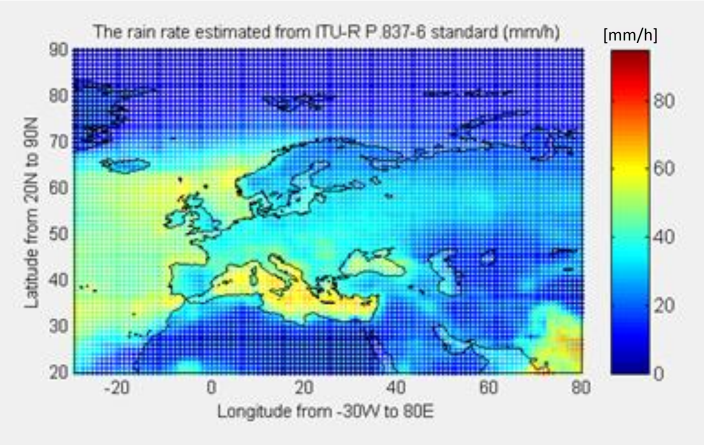


FIGURE 5. ITU-R 873.6 Rainfall Rate (*IRR*)

Rainfall has direct impact on total loss on a radio link. There are also other impacts but as mentioned earlier, at high frequency bands (Ku, Ka), rainfall will take a dominant portion of the total loss. A considerable difference in rain rate will therefore lead to a significant difference in total loss and link budget as well.

Link budget at IRR and MRR

In radio communications systems, the Equivalent Isotropically Radiated Power (*EIRP*) is the amount of power that would have to be radiated by an isotropic antenna to produce the equivalent power density observed from the actual antenna in a specified direction. The EIRP is still a function of direction, and not assuming power is radiated isotropically. Figure 6 shows fundamental components of both satellite up-link and down-link. In this figure, EIRP at space station ($EIRP_S$) is the value that normally provided for each satellite at a certain direction or area. For example, EIRP of a specific GEO satellite, ASTRA-4A [11], which will be used in the coming evaluations, is showed in Fig. 7.

Theoretically, EIRP in [dBW] at a space station can be described as,

$$EIRP_S = 10log(P_S) + G_S - L_{FeederS}\,, \tag{1}$$

where P_S (W) is transmitted power of space station, G_S in [dBi] is transmitting antenna gain and $L_{FeederS}$ is loss caused by feeder of transmitting station.

Link budget of a radio link is actually the receiving power for example at a ground station (P_G in Fig. 6), and can be written

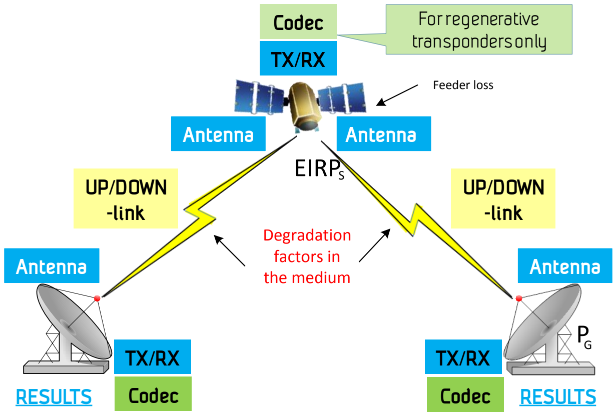
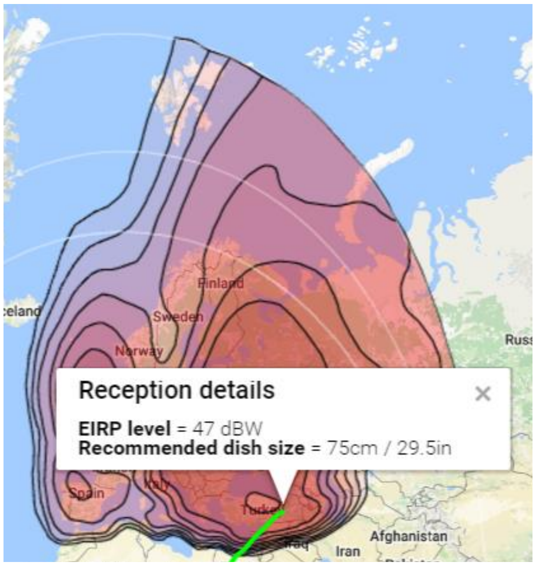


FIGURE 6. Diagram of Uplink, Downlink and EIRP in satellite systems



Reception details

EIRP level = 47 dBW
Recommended dish size = 75cm / 29.5in

FIGURE 7. EIRP of ASTRA-4A

as follows,

$$P_G = EIRP_S + 10log(P_S) + G_S - L_{medium} - L_{FeederG}\,, \tag{2}$$

where G_S [dBi] represents the gain at receiving antenna, L_{medium} represents the losses relate to transmission medium caused from atmospheric gases, cloud, fog, rain etc. and $L_{FeederG}$ is for eventual losses at feeder of receiving station.

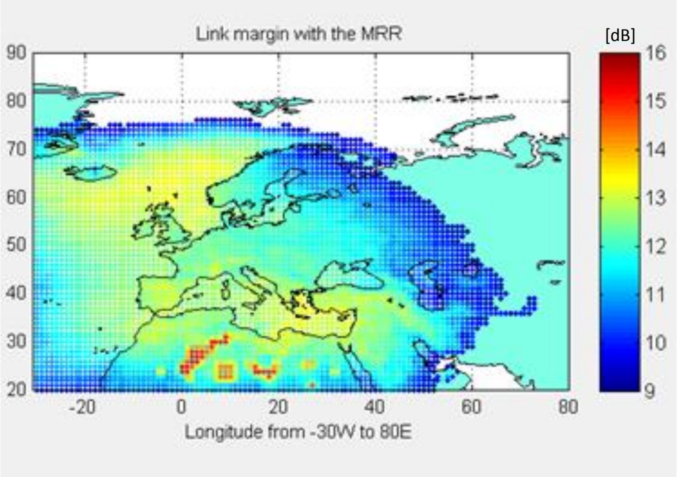


FIGURE 8. Link budgets of ASTRA-4A with MRR

Equation (2) shows that at a specific location or area with the same $EIRP_S$, the difference in link budget is equal to the difference in the losses. A part of this consequence in deviation is caused by rain. In this case of evaluations, the difference between MRR and IRR are the root reason of making link budgets different. This is a necessary step when converting from rainfall rates deviation to final link budget difference.

In order to visualize the link budget difference, an example with ASTRA-4A (this GEO satellite provides coverage in the High North region above Norway) is used for evaluating. At a certain location, EIRP value is not changed so the evaluation will not be changed if assuming EIRP is constant. With a constant EIRP (assuming at 45 [dBW]), link budget for *MRR* and *IRR* cases are showed in Fig. 8 and Fig. 9, respectively. At different locations on the map, the differences in link budgets can be different. A mapping between the color at a location on the map and the color column on the right side (of each map) will provide the difference estimated in decibel (dB). Usually *IRR* is smaller than *MRR* (this gap is especially visible at the high latitudes), so the link budget a these areas will be larger with *IRR* and smaller with *MRR*. The difference becomes larger at the northern and eastern sides of the satellite location (with ASTRA-4A it is on the Equatorial plane at a longitude of 5° East). At these locations, the ground station is locating farthermost from satellite; hence, rain effect as well as the difference in link budget become largest.

The Fig. 10 further shows the difference in [dB] when classifying it in 5 levels (from Level-1 (the difference: 6-8 [dB]) to Level 5 (the difference: 0 [dB])). As mentioned earlier, this difference also means the extra degradation between the normal case and the worst case regarding to the losses caused by rain (representative with rainfall rate values). As a result, at the worst

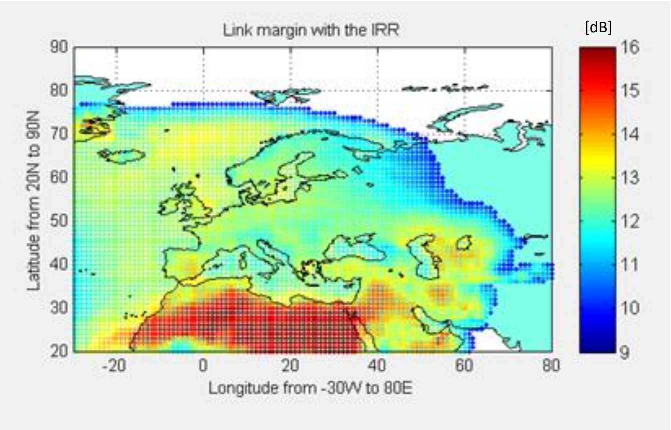


FIGURE 9. Link budgets of ASTRA-4A with IRR

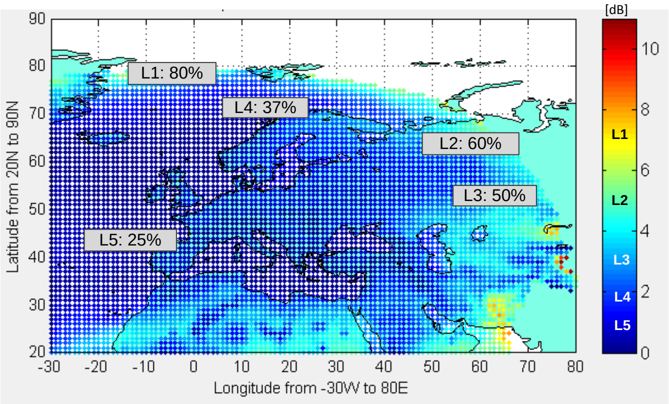


FIGURE 10. Plotting the difference of link budget or rain losses

case, the system needs to reduce the data rate or bandwidth in order to maintain service quality as in the normal case. The conversion between the extra loss and bandwidth reduction will be,

$$BW_d rop = (1-\frac{1}{10^{\frac{\text{loss}}{10}}})100(\%) \qquad (3)$$

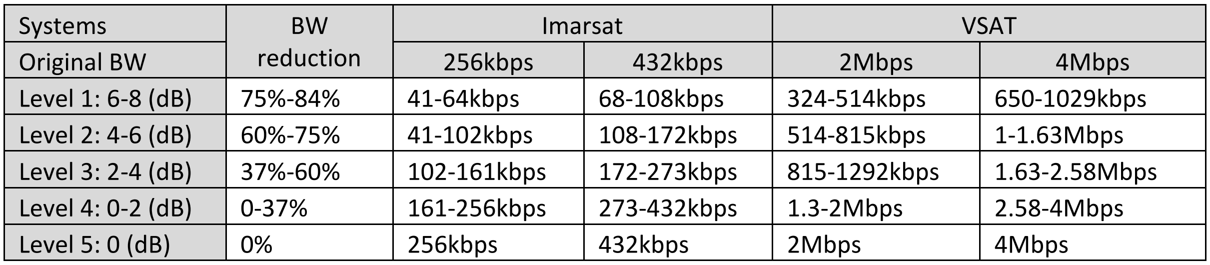
Applying the five levels of losses in Fig. 10 into Eq.(3), the bandwidth losses can be shown in Fig. 11 with different examples on the satellite systems such as Inmarsat and VSAT. In this figure, original bandwidth means the bandwidth in normal case of rain loss, and the new bandwidths are the ones with respective loss levels described on the first column.

When bandwidth loss is considerable it will definitely affect to the operations of systems that require intensive data exchange with its control room for example in many Integrated Operation (IO) systems. For offshore oil and gas industry, even in the case offshore systems can operate themselves without controlling signals from shore, many bandwidth demand services have to suffer from this bandwidth drop (e.g. welfare/entertainment, internet services, video conferencing, video telephone, and so on). If this situation lasts for a long period, it will anyway affect to daily working on offshore installations and supporting vessels.

METHODOLOGY FOR SERVICE PERFORMANCE EVALUATION

Figure 12 describes the method used for evaluating performance of a service (or services) when its characterizations (see Table 2) are predefined. The functional blocks are distinguished with these color codes: yellow is for major information sources, green is for main processes and orange is for main results. Following this methodology, these data is essential for a service evaluation: satellite system, channel utilization mechanism, system bandwidth, rainfall rate data (*ECMWF*), list of services with parameters. In order to execute these evaluations, several intensive processes were established and simulated such as: rainfall rate data extraction from needed geographical area, *IRR/MRR* estimation, Bit-Error-Rate (*BER*), Packet-Error-Rate (*PER*).

An important parameter of any service is its priority which has briefly been explained earlier. This priority reflects the importance of a service. It is also the measure to choose data packets amongst the packets from various services that can use or want to use a channel at a specific time. This happens when there are many packets from different services and demanding to use the channel (need to send its data) at the same time. For channel utilization, assuming that at an individual time, the service (with the highest priority) will use all of the bandwidth available. If there are many services having data arriving at the same time and with the same priority, the one is using the channel will continue its transmissions until its packets are transmitted. In the case a high priority packet arrived and the channel is occupied by others, this packet just needs to wait until the on-going packet transmission is finished. If the arriving packet has lower priority than the ones using the channel, it has to wait until all of these packets transmitted. If this priority is even lower than the priority of the packets are waiting for the channel's availability, this packet has to wait for the packets were on queue. In conclusion, a lower priority service data has to wait for other service's data which have higher priority. How the packets of a service are generated is decided by the frequency it uses the service. This is one of the service's parameters (in Table 2). Based on this information, the packet generation block will create the data packets for each service and also provide arrival times of these packets to the evaluation process. The next section will discuss on the scenarios to be used for evaluating services performances.



Systems	BW reduction	Imarsat		VSAT	
Original BW		256kbps	432kbps	2Mbps	4Mbps
Level 1: 6-8 (dB)	75%-84%	41-64kbps	68-108kbps	324-514kbps	650-1029kbps
Level 2: 4-6 (dB)	60%-75%	41-102kbps	108-172kbps	514-815kbps	1-1.63Mbps
Level 3: 2-4 (dB)	37%-60%	102-161kbps	172-273kbps	815-1292kbps	1.63-2.58Mbps
Level 4: 0-2 (dB)	0-37%	161-256kbps	273-432kbps	1.3-2Mbps	2.58-4Mbps
Level 5: 0 (dB)	0%	256kbps	432kbps	2Mbps	4Mbps

FIGURE 11. Conversion between extra loss and bandwidth drop

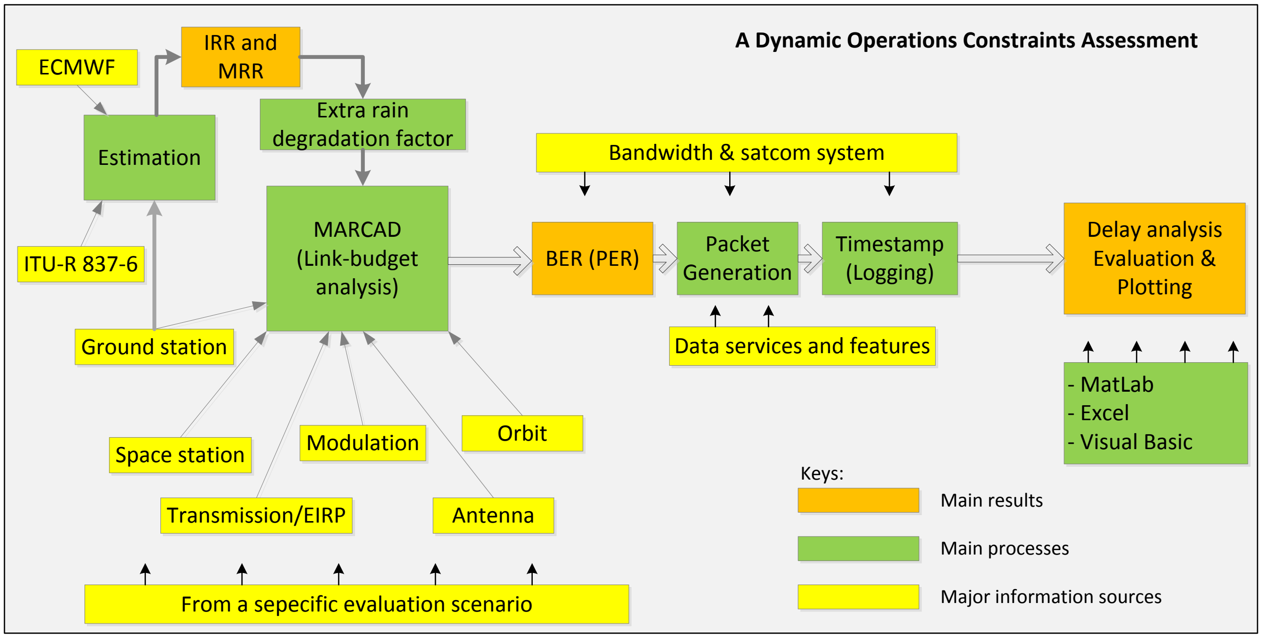


FIGURE 12. Methodology for evaluating a service performance

EVALUATIONS SCENARIOS

Scenarios

A list of services is defined with the demand, usage frequency, priority and other parameters are shown in Table 2. These parameters are kept unchanged during the evaluations for their performances at following geographical locations starting at Position #0 to Position #3 (see Fig. 13). Due to the external degradation factor at each position is different from each other, each position could be seemed as an evaluation scenario where we search for performances of those services. The scenarios are as following:

1. Pos. 0: 56.5°N 3.2°E (Ekofisk installation)
2. Pos. 1: 68°N 10°E
3. Pos. 2: 73.5°N 27°E
4. Pos. 3: 78°N 27°E

Assumptions

With the intention is to examine how the service performances will vary when the location of operation moves further North with the targets are on Geostationary Earth Orbit (GEO) satellites. Iridium satellites system can provide a global coverage but it is limited in both bandwidth (capacity) and connection

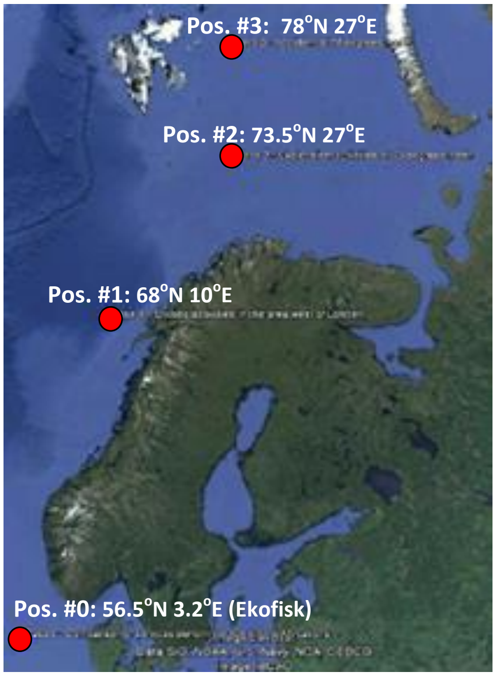


FIGURE 13. Geographical locations at the four scenarios

breaks (reliability) [7]. VSAT and Inmarsat are therefore chosen for the evaluations with bandwidth assumptions as following:

1. Bandwidth:
   (a) VSAT: 2048kbps and 4096kbps
   (b) Inmarsat: 256kbps and 432kbps
2. EIRP (Equivalent Isotropic Radiated Power):
   (a) VSAT (ASTRA-4A at 5°E, refer to Fig. 7):
      i. Pos. 0: 47 dB
      ii. Pos. 1: 45 dB
      iii. Pos. 2: 44 dB
      iv. Pos. 3: 43 dB
   (b) Inmarsat: assumed EIRP is a constant, at 45 dB.
3. Extra rain loss:
   (a) Pos. 0: 0 dB (0% BW reduction)
   (b) Pos. 1: 1 dB (20% BW reduction)
   (c) Pos. 2: 3 dB (50% BW reduction)
   (d) Pos. 3: 5 dB (68% BW reduction)

   These losses are the differences between MRR and IRR at those position scenarios, following the results from Fig. 10.
4. Feeder loss: assumed zero at both transmitting and receiving stations.

Evaluation Criteria

The criteria used for these evaluations is *Satisfactory Rate*, which is defined as the ratio between the number of packets arrived at its destination not later than the deadline and the total number of packets transmitted (excluding the packets were retransmitted due to errors).

Bit-Error-Rate (*BER*) and Packet-Error-Rate (*PER*) are not directly used for evaluation. They however are used for determining the retransmission packets. These packets will affect directly to the packets queuing, which afterward may lead to a worse satisfactory rate due to a longer queue of retransmitted packets.

SIMULATION RESULTS

Evaluation of Satisfactory Rate

The services used in these scenarios are shown in Table 2 and the method used for evaluating services performance is described in Fig. 12. All of the inputs will be taken into the evaluation processes and the performances of these services will be analyzed for both Inmarsat and VSAT data links with the main criteria is "$SatisfactoryRate$". Figure 14 and Fig. 15 show the satisfactory rates for the services in the cases of using Inmarsat and VSAT data links, respectively. In these figures, at each service (stands on the horizontal axis) there are maximum of 8 different-color columns presenting satisfactory rates of that service in eight sub-cases. These sub-cases are formed by 2 groups of 4-columns where each group is for one case of bandwidth (e.g. 256kbps or 432kbps for Inmarsat; 2048kbps or 4096kbps for VSAT). Each column (of the total 4) presents the satisfactory rate at a specific geographical location (ranges from Pos.0 to Pos.3).

When a column standing for service performance at one position is missing, it means that the according service operates at that position was not satisfied anything or this service was unable to use (unavailable). It will be not satisfied at all if all of the data packets arrived at its destination later than the expected deadline; service is not available if none of its data packets arrived at its destination. There was an improvement in service performance shown when changing from Inmarsat (Fig. 14) to VSAT (Fig. 15). Specifically, the *Satisfactory Rates* for the services become higher and there are fewer missing columns in each service group. Some specific comparisons for services performances with Inmarsat and VSAT are as follows: a) The first group of services that get similar and high satisfactory rates: *Emergency call to Shore*, this service got 98% of satisfactory in both Inmarsat and VSAT (regardless the bandwidth is 256/432kbps (Inmarsat) or 2048/4096kbps (VSAT)) at only the latitudes below 73.5°North. Above this latitude, emergency call service to shore is not satisfied at all. This means that all of the conversations were being delayed more than its maximum allowed delay (1 second - see Table 2) and it does not mean that the service is

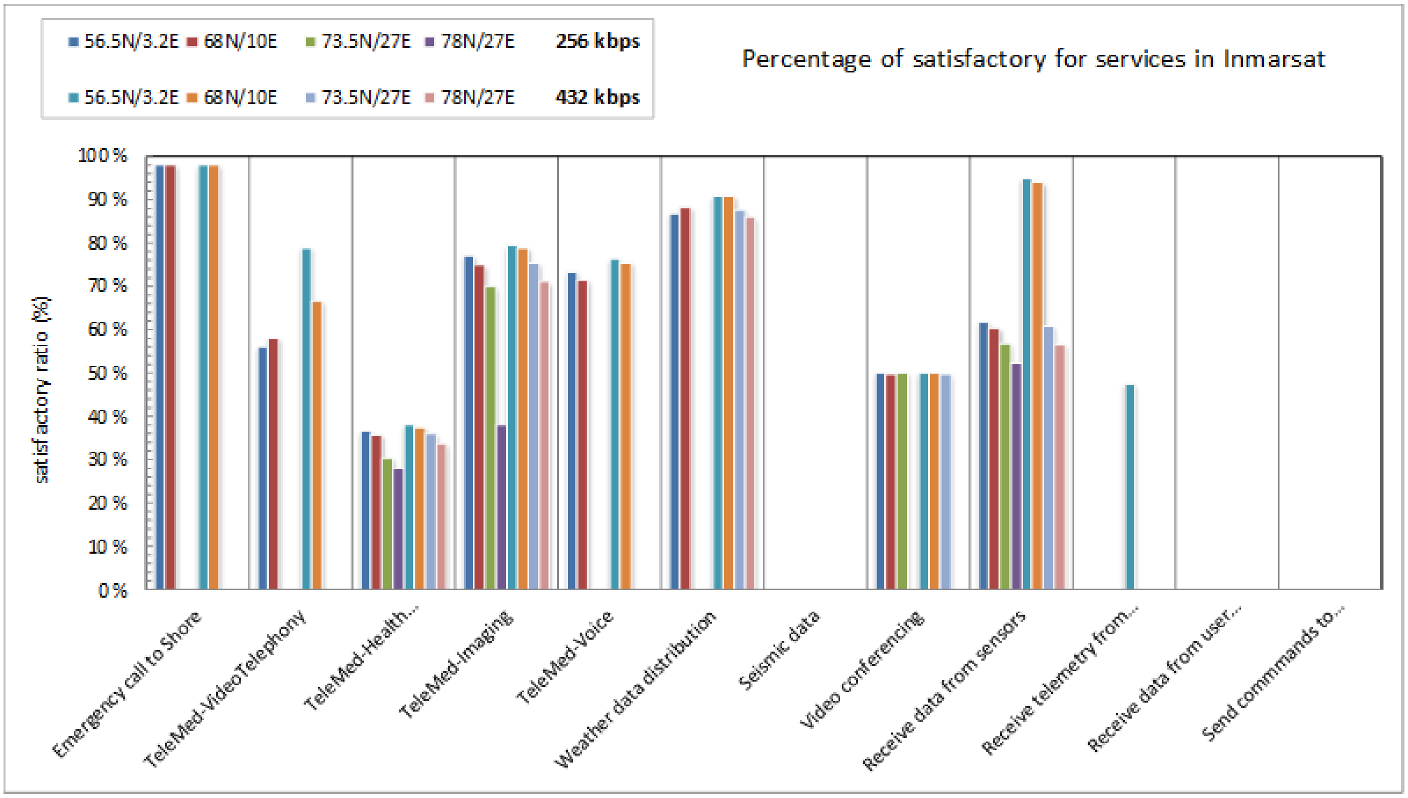


FIGURE 14. Performance of services at 4 scenarios with Inmarsat (256/432kbps)

unavailable. If the maximum allowed delay for this service is larger than 1s, the performance may be increased. b) The second group for services outperform in VSAT: these services became highly satisfied with VSAT link but they were not satisfied at all with Inmarsat data link. They are the last three services counting from the right hand side (Fig. 14 and 15). c) *Seismic Data* service: With the service configuration in Table 2, this is the one was unavailable with Inmarsat but got roughly 27%-61% of satisfactory rate when changing its location from Ekofisk to 73.5 degree North at VSAT-2Mbps (and is unavailable at 78 degree North even assigned with maximum delay of 5 minutes and a 2Mbps data link). At 4Mbps, the satisfactory however became better, ranges between 37% and 80%. At 78øN, 37% of expected seismic data (5GB daily) was still being sent to shore within the delay of 5 minutes if the link is VSAT and at 4Mbps.

Workable and Un-Workable Services

For an easy reading of the results, satisfactory rates are classified into following highlights:

1. 70%-100%: It has color close to green (relative good satisfactory rate)
2. 50%-70%: It has color close to orange (the satisfactory rate is just average, not too high or too low)
3. 0-50%: It has color close to red (low and very low satisfactory rate)

With this conversion, the results showed in previous Fig. 14 and Fig. 15 can be represented in the following Fig. 16 and Fig. 17, respectively.

One can see many services from Fig. 16 in *red* color especially from the latitudes of 73.5°N or higher. The voice related services are usually seriously affected at high latitudes (e.g. 73.5 or 78 degrees North). Many file transfer services showed that they were usable but at only a low ratios of satisfactory means poor performances. Looking at Fig. 17, there is a positive change from *red* to *green* with a significant improvement located at *file transfer* service groups. These services were not partly or fully satisfied with Inmarsat data link but they became more satisfied with VSAT data links thanks to be able to use higher bandwidths in the later case.

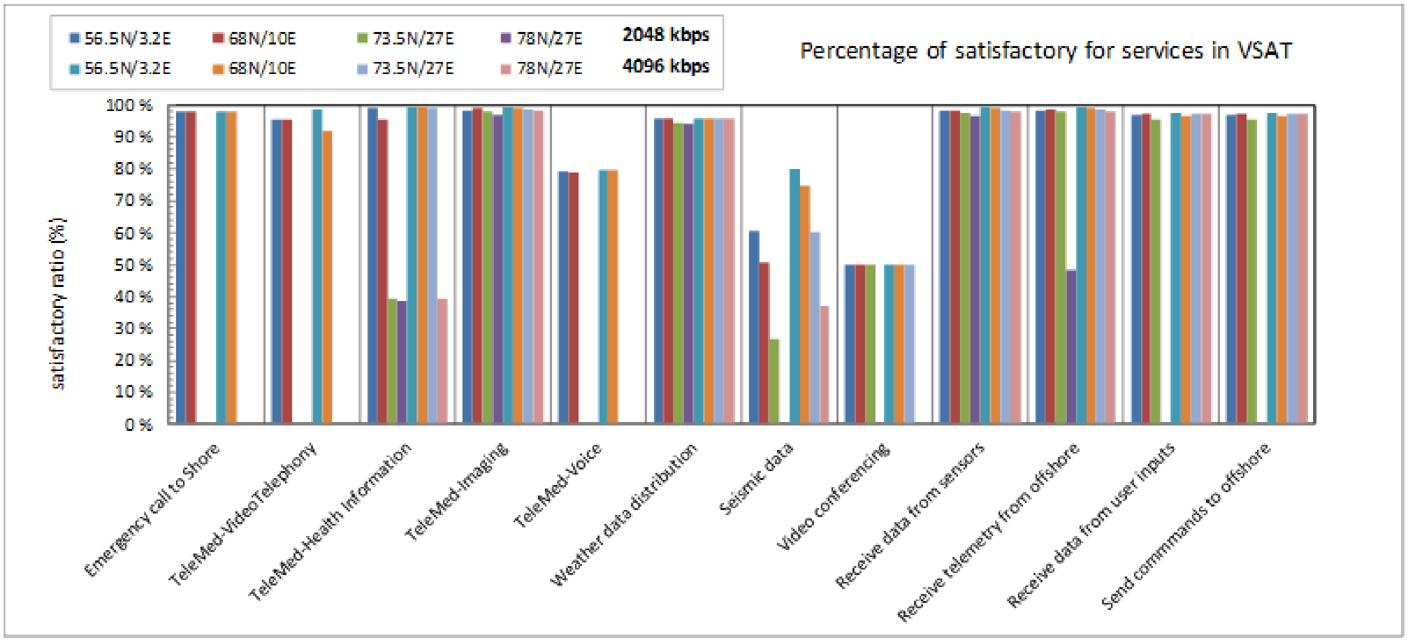
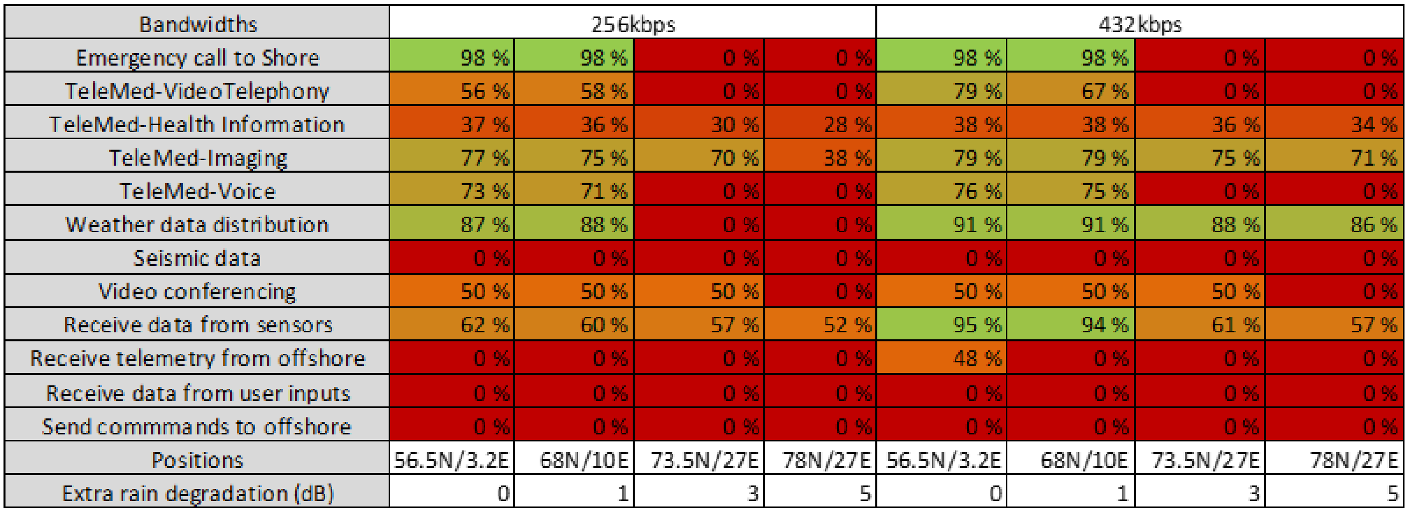


FIGURE 15. Performance of services at 4 scenarios with VSAT (2048/4096kbps)



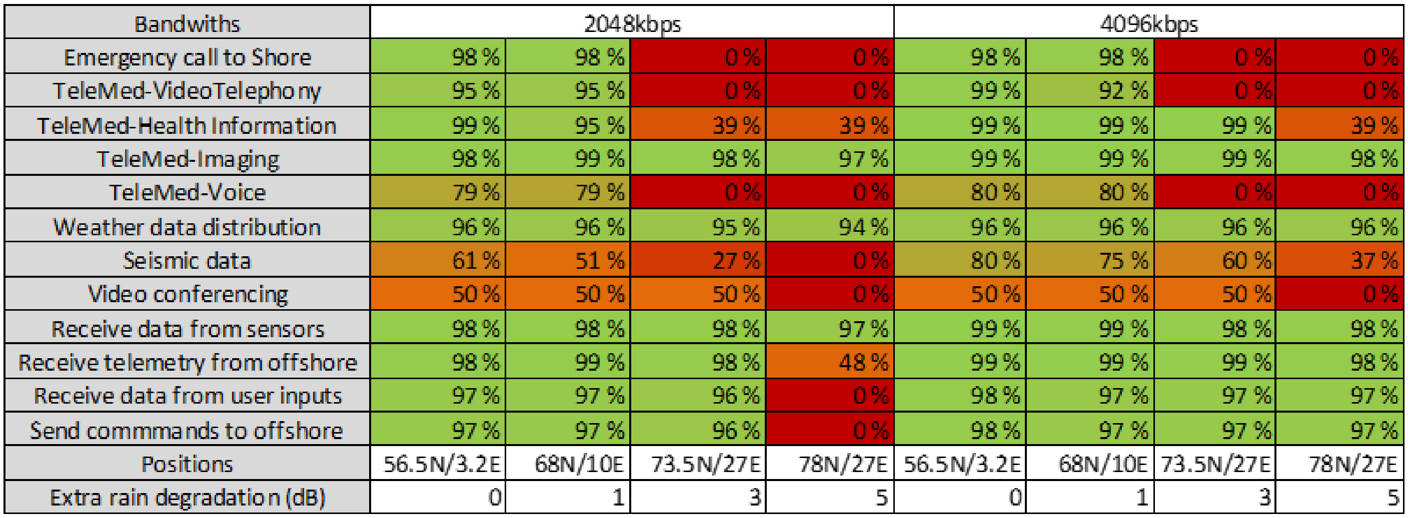
Bandwidths	256kbps				432kbps			
Emergency call to Shore	98 %	98 %	0 %	0 %	98 %	98 %	0 %	0 %
TeleMed-VideoTelephony	56 %	58 %	0 %	0 %	79 %	67 %	0 %	0 %
TeleMed-Health Information	37 %	36 %	30 %	28 %	38 %	38 %	36 %	34 %
TeleMed-Imaging	77 %	75 %	70 %	38 %	79 %	79 %	75 %	71 %
TeleMed-Voice	73 %	71 %	0 %	0 %	76 %	75 %	0 %	0 %
Weather data distribution	87 %	88 %	0 %	0 %	91 %	91 %	88 %	86 %
Seismic data	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Video conferencing	50 %	50 %	50 %	0 %	50 %	50 %	50 %	0 %
Receive data from sensors	62 %	60 %	57 %	52 %	95 %	94 %	61 %	57 %
Receive telemetry from offshore	0 %	0 %	0 %	0 %	48 %	0 %	0 %	0 %
Receive data from user inputs	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Send commmands to offshore	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
Positions	56.5N/3.2E	68N/10E	73.5N/27E	78N/27E	56.5N/3.2E	68N/10E	73.5N/27E	78N/27E
Extra rain degradation (dB)	0	1	3	5	0	1	3	5

FIGURE 16. Workable and unworkable services when using Inmarsat (256/432kbps) at 4 scenarios

CONCLUSION

The paper has provided various aspects of operations challenges in the high North regions including the Arctic. The challenges here are on data communications, which is essential for exchanging data between offshore vessels or installations and shore (e.g. the control room). The paper focuses on the analysis for Oil & Gas offshore services; but it is easy to broaden the services categories as well as to extend to the services in other sectors such as maritime shipping, fishing and aviation.

Simulation results and analysis have shown the *Satisfactory Rates*, the criteria for service performances, of the defined services in Oil and Gas offshore industry at various latitudes and as-



Bandwiths	2048kbps				4096kbps			
Emergency call to Shore	98 %	98 %	0 %	0 %	98 %	98 %	0 %	0 %
TeleMed-VideoTelephony	95 %	95 %	0 %	0 %	99 %	92 %	0 %	0 %
TeleMed-Health Information	99 %	95 %	39 %	39 %	99 %	99 %	99 %	39 %
TeleMed-Imaging	98 %	99 %	98 %	97 %	99 %	99 %	99 %	98 %
TeleMed-Voice	79 %	79 %	0 %	0 %	80 %	80 %	0 %	0 %
Weather data distribution	96 %	96 %	95 %	94 %	96 %	96 %	96 %	96 %
Seismic data	61 %	51 %	27 %	0 %	80 %	75 %	60 %	37 %
Video conferencing	50 %	50 %	50 %	0 %	50 %	50 %	50 %	0 %
Receive data from sensors	98 %	98 %	98 %	97 %	99 %	99 %	98 %	98 %
Receive telemetry from offshore	98 %	99 %	98 %	48 %	99 %	99 %	99 %	98 %
Receive data from user inputs	97 %	97 %	96 %	0 %	98 %	97 %	97 %	97 %
Send commmands to offshore	97 %	97 %	96 %	0 %	98 %	97 %	97 %	97 %
Positions	56.5N/3.2E	68N/10E	73.5N/27E	78N/27E	56.5N/3.2E	68N/10E	73.5N/27E	78N/27E
Extra rain degradation (dB)	0	1	3	5	0	1	3	5

FIGURE 17. Workable and unworkable services when using VSAT (2048/4096kbps) at 4 scenarios

sumptions. These cases include the combinations of four different geographical locations (from Pos.0 to Pos.3) with two satellite data link types (Inmarsat and VSAT) and the bandwidths (two values for each type of data link). The results were diversified but a common conclusion is that, service performance can become worse when moving its operating location to further high North regions. In addition, the most vulnerable service was the ones related to voice services; specifically, this time-critical service group can work well at Position #0 and Position #1 and its performance was considerably degraded at higher latitudes (at Positions #2,3).

Earlier analysis about rain showed that the worst case of rainfall rate at high latitude regions may significantly affect services performance. The evaluations were done with GEO satellite links in Ku band; the effect will be larger at higher frequency bands such as Ka band. In order to overcome this issue, one way is to reduce the data rate (or bandwidth) of the link or have to reserve a larger margin for the radio link. The specific amount can be used for estimating of bandwidth reduction or increasing link margin was introduced in Fig. 10 and Fig. 11 . It is difficult to link between these evaluations and the amount intentionally added to link budget of new satellite links. But one can see an example with Norwegian Thor-7 satellite. EIRP (see Fig. 18) in Thor-7 is higher than EIRP used with other existing satellites, for instance ASTRA-4A, that we used for evaluations in this paper. EIRP used for Thor-7 satellite is about 48-52 dB and EIRP used with ASTRA-4A was 41-47 dB. With this extra addition (5-7 dB) to final link margin, according to our estimation of extra rain loss (applied in the Ku band) for the worst case in the high North regions, these amount are quite similar. The evaluations in the paper can also be used in other cases for service performance evaluations and in satellite links design.

FIGURE 18. Footprint and EIRP (48-52 dB) of Thor-7 Satellite at Ku band

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