Efficient allocation of 6G LEO downlink resource via software defined Ground Segment MODEM

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***Abstract* — Satellite requires large scale investment, which needs to improve the efficiency in using the bandwidth resource, not only limited but expensive. This can be possible by allocating more resource to areas with more demand, rather than evenly to other areas also of no or less demand. It will be more important to minimize the additional latency that may rise additionally by those additional allocation process, as latency is the most critical issue for advanced 6G network. This paper is about why and how to address above 2 tasks.**

This Beam Hopping technology can be applied to both GEO and LEO. However, it will be more effective for LEO than GEO, as LEO resource will be more wasteful by allocating the resource seamlessly to areas of no or less demand, especially in areas like open sea, for instance, which covers more than 70% of the globe while GEO coverage is already well designed to accommodate the relevant demand accordingly from the beginning.

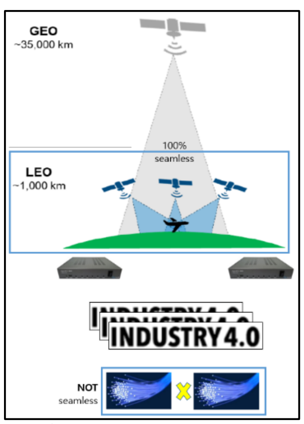

Figure 1. GEO vs LEO

Keyword: LEO, Terminal modem, Beam Hopping (BH), DVB-S2X AnnexE, Superframe(SF)

I. INTRODUCTION

In satellite network, data demand is not uniform in time and place, but fluctuates all the time. Accordingly, some areas under the beam may require more bandwidth than the allocated bandwidth. Conversely, some may require less bandwidth than allocated in many cases. In the former case, additional allocation of satellite bandwidth would be regrettable, and in the latter case, expensive satellite bandwidth would have been wasteful, where a huge amount of waste may occur every day when calculating the life span of a satellite.

Likewise, if it is used efficiently, it may create an enormous added value every day. Therefore, if satellite resources are flexibly shifted and reallocated between areas according to real-time demand for data, more efficient use of satellite resources will become possible.

For example, a specific terminal that requires more data then had better be allocated the resources for a longer period of time in the service area i.e. quality service will become possible by minimizing waste in the idle areas, but instead allocating more to the busier areas, maximizing the efficiency. This is, Beam Hopping technology. For this, if the packet header / data frame format structure suitable for each data transmission requirement or each satellite communication environment is optimally selected and applied, the most efficient use of satellite resources with additional but minimized latency service can be achieved.

In existing communication satellites, a beam is fixed once launched and the beam coverage cannot be changed if not manually moved, which would shorten the life span of the satellite by consuming much power. However, if the beam hopping technology that makes the shape of the beam with a different co-efficient for each terminal is applied, the illumination will be variably changed every moment in a phase array method. In other words, if each beam is serviced with a time difference to cover all service areas as a whole, and by selecting and intensively supporting a small area that requires intensive traffic at a given time, the effect of improving link availability of the entire communication and reducing the cost of ground station equipment via smaller RF, thanks to improved G/T and EIRP, will be possible. In particular, it is useful to prevent wastage of satellite bandwidth for increasing the efficiency. This technology will be further useful for mobile applications such as ships and airplanes. The satellite will detect the received signals while changing the regions by time zone and adjust the coefficient in real-time, using the resource in the most efficient way.

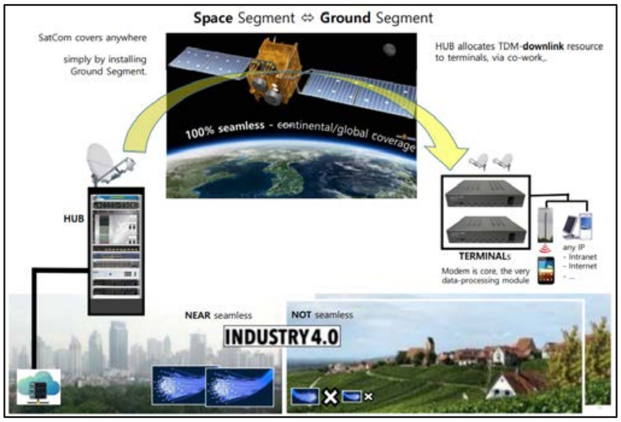

Figure 2. Downlink from HUB to terminals

Such Software Defined Radio beam's flexible resource reallocation technology that can support these functions can respond to uplink and downlink transmission respectively. However, currently in uplink transmission, the efficiency of using satellite resources has already been improved due to the development of active satellite resource allocation technologies such as DVB-RCS2 MF-TDMA. But in downlink transmission, it is common to apply the fixed allocation method, still according to the current DVB-S2 / DVB-S2X TDM standard, which transmits evenly via fixed resource allocation, not fully efficient. Accordingly, a plan to further improve the efficiency of using the limited satellite resources for TDM downlink is needed. First, this paper aims to review an active reallocation plan for satellite resources to improve the efficiency in using downlink.

Active resource allocation in realtime can be applied by using DVB-S2X AnnexE superframe based downlink transmission. Reallocation on-demand is possible more flexibly, compared to the existing fixed resource allocation, which is possible to reallocate more resource to a terminal that requires more data traffic. Similarly, limited satellite resources can be saved by allocating less resource to terminals that do not require that much data traffic. Another good result is that, it will be possible to extend coverage wider for service providers and operators, enabling more user subscriptions.

II. LEO Beam Hopping Formats

Current conventional satellite resource allocation technology is a fixed method, so satellite resources are inevitably wasted, fixedly allocated to all terminals within coverage regardless of the destination terminal of the packets, after being googled. Then, the modem that requested the very packets, filters the MAC address information of all packets it receives, and if the packet that matches with the MAC address of the modem, which was the original requesting party of the data, it will be able to demodulate the packets and take the information. But the other packets, requested by the other modems with indifferent MAC address, will naturally be drained or dumped away. Therefore, this broadcasting concept based fixed allocation method of downlink inevitably wastes satellite resources, by allocating resource also to the other modems with indifferent MAC address, which have nothing to do with the packets requested to be googled by the very modem.

Below diagram shows how this can be possible. HUB schedules BHTP (beam hopping time plan) for active reallocation, in consideration of terminal location in time domain. The modem of the BH compatible SF structure sets the resource allocation schedule according to the BH cycle, which selects only the area where the modem that requested the information is installed or operational, and enables re-allocation to transmit accordingly.

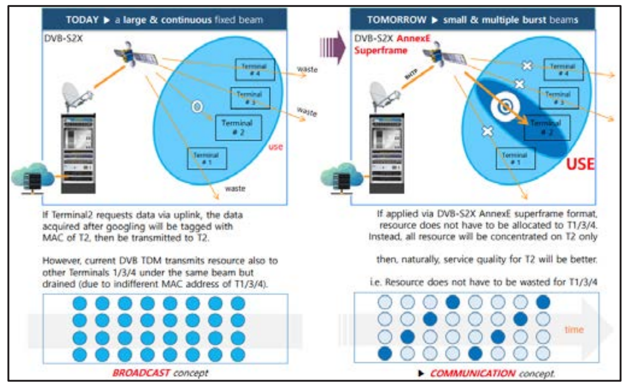

Figure 3. Legacy downlink vs Beam Hopping

What should be considered next for efficiency improvement is, to minimize the latency, where additional latency inevitably occurs due to the additional process for reallocation. i.e. Some application may have higher value on efficiency but some may prefer faster speed with less latency, rather than efficiency itself.

For example, in case the destination is always fixed, while traffic should be transmitted in large volume, then the packets may not need the heavy Header, which is necessary for accommodating the complex BHTP algorithm, as the complex and heavy Header would naturally cause burden for both the satellite and the network, rendering additional latency. So, these packets had better not wait in queue to be reallocated for transmission as per the BHTP but be transmitted as soon as filled-up in the container of the packet or arriving at the modulator in HUB.

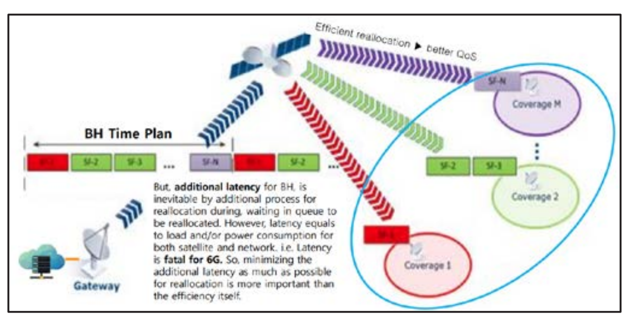

Figure 4. Consideration for 6G

So, additional latency for BH, is inevitable by additional process for reallocation during, waiting in queue to be reallocated. However, latency equals to load and/or power consumption for both satellite and network. i.e. Latency is fatal for 6G. So, minimizing the additional latency as much as possible for reallocation is more important than the efficiency itself.

Such issue can be handled by providing various satellite resource reallocation technology platforms via DVB-S2X AnnexE SF(superframe) for the optimal LEO service platform. There are various Formats suitable for diverse LEO applications and has the following characteristics, compared to the conventional protocol.

Unlike previous formats, Format 5 / Format 6 / Format 7 can take the SF length variably, and unlike the previous irregular frame length structure, constant SF length and simplified resource allocation grid improves data search probability. With regular pilot grid, it supports rapid synchronization recovery after imaging as well as simplifies efficient phase tracking. All formats 5 / 6 / 7 can be transmitted with a time difference. If BHTP is set differently for each gateway (i.e. cluster) in the same satellite or transponder and transmitted in different formats for each cluster, only the contents actually supported by the SF Format Indicator of the receiver will be filtered and demodulated by the receiver. Naturally, unsupported Format(s) will have to be bypassed or drained via de-activation. So, we need to understand features of each Format, in order to select the most appropriate Format for each service application.

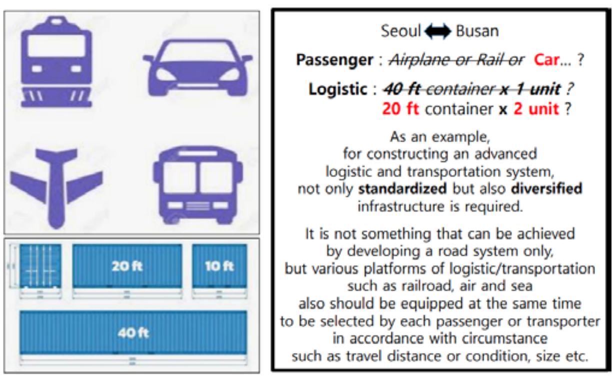

Figure 5. Standard & diverse Formats

However, we have to bear one thing into consideration. Unlike legacy technology, BH LEO service is differentiated in targeting more future oriented broadband market 6G i.e., BH will be required for 6G platform that can satisfy various applications with various requirements especially of less latency. Therefore, the platform should be able to support the two factors of both resource efficiency (to maximum) and latency (to minimum) at the same time.

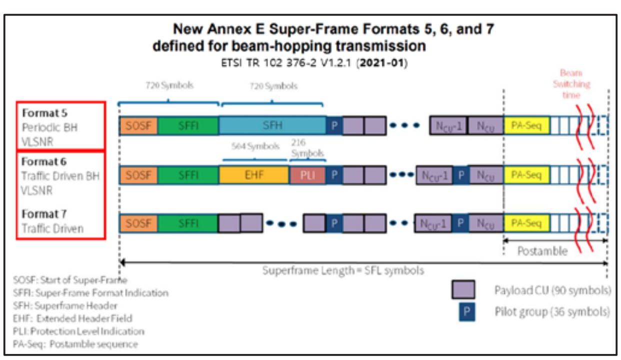

Figure 6. Formats 5, 6 and 7

Firstly, Format 5 has the following characteristics.

- SF length can be diversified to cope with different symbol rates on the same or different dwell time per cell, and high efficiency roll-off filtering and wideband time-slicing and bonding are supported to increase reception speed.

- If the coverage is wide but the cell data demand change is not so big, it is suitable for such a network with repeated or periodic traffic requests.

- General Internet applications usually show a symptom that, the data demand peaks around 8-10 a.m. working hours at the start of the day and, minimum between 3-5 a.m. idling hours just before daybreak, will be repeated almost every day by region and/or hour 24/365 thus predictable to some degree in advance. So, it can be possible to reduce congestion and load by reflecting in advance of the resource reallocation scheduling algorithm of the repeating pattern, which is most suitable for Format5.

However, allocation by advance planning inevitably causes additional delay. So, it is not suitable for applications that require high-speed data, not repetitive or periodic. That is, if the allocated resources per cell cannot be used sufficiently due to the waiting delay of the BHTP for which the time is already set, the efficiency will be inevitably reduced by the inevitable and additional latency. In reallocation, it would be desired if it is possible to reduce power consumption as well as well as reducing the delay involved in the repetitive process. Therefore, the necessity of Format 6 / 7 arises.

Format 6 / 7 are suitable for delay sensitive, but traffic-oriented reallocation where the traffic pattern is not regular i.e. not repetitive. Therefore, it is suitable for mobile services with large changes in traffic demand and applications that require realtime response or are sensitive to latency. In particular, in regenerative OBP repeater, it is advantageous to send multiplexed packets to users immediately without waiting delay for packets whose illumination time is not regular or repetitive. Unlike pre-scheduled format in which excessive queuing delay is inevitable by queuing packets to be transmitted in a row, it is possible to reduce delay time and improve the efficiency of using satellite resources by immediately sending each packet as a packet by packet basis (Point & shoot) without pre-scheduling. This is an illumination strategy wherein packets are transmitted as they arrive, and not according to a predefined BHTP.

When interference occurs due to simultaneous transmission to adjacent channels, some kind of coordination is required and the pilot is always turned on to maintain communication even under unpredictable fluctuations.

Especially, Format 6 is

- Suitable for mobile application services such as airborne/maritime, minimizing noise and radio interference, supporting VLSNR (around -10dB) and facilitating sync recovery and scramble simplification

- Maintains "Keep Alive" state of receiver to support short dwell time for cell of mobile service.

- By using a simple code instead of the SF Header, the overhead is small and efficient, and since the duration is variable, it is possible to elastically support the illumination time and extend the SF length.

- The case of mobile applications such as airborne and maritime without repeated patterns, unlike fixed and repeated pattern Internet application on land, may have to be based on traffic-driven Format6, where data protection is more important in data slicing / bonding and error recovery for supporting mobility than efficiency of bandwidth itself.

In contrast, Format 7

- Can be called a light version of Format 6, and since hopping transmission time or routing information is limited by traffic-centric allocation, interference between cells and avoidance of shared channel in neighboring cells must be considered in scheduling design.

- In Format 6, the SF length is determined by the received SNR, but in Format7, the level indicator is constant. So the SF length is not determined by the received SNR and can be freely extended. Therefore, the data rate efficiency is high even without VLSNR support, that is without SF Header can be applied. Naturally, it is very efficient with small or simple overhead, and it is easy to respond to real-time traffic with ultra-low latency because traffic is transmitted immediately without queuing, as soon as they arrive.

- When the destination is fixed while large-capacity transmission is required such as ISP/Backhaul, the efficiency of resource use will have to be improved maximally by loading the data into a full container of the packet structure, that can be done without the complex and heavy Header. Then the packets can immediately, upon arrival at the modulator, be transmitted without waiting in queue to be reallocated, that would otherwise cause additional latency by the heavy burden BHTP algorithm at Header. So, this Format7 can eliminate or minimize delay, via traffic-driven Point & Shoot basis.

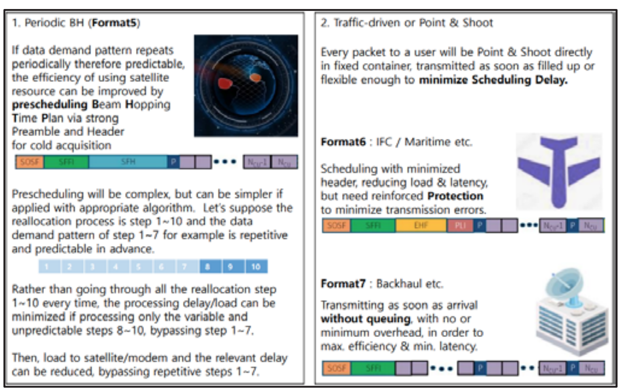

Figure 7. Formats' summary

Control and synchronization information is transmitted separately in parallel, so it does not cause cycle time delay and minimizes radio interference with different frequencies or scrambles.

Then, synchronization of data transmission according to frame boundary and hopping or switching will be the core of the technology. In particular, unlike GEO, in the case of LEO, high speed switch-over Doppler compensation between satellites and VLSNR response will be the biggest technical challenge to overcome.

The concept of SF made it possible to introduce a new topology called precoding, flexibility and variability support for non-uniform & time-varying became possible. It improves protection against conventional non programmable scrambling, and by using dummy data, it not only prevents important data damage during switching, but also simplifies synchronization and improves reliability with the burst mode SF structure in VLSNR frame search for each symbol, and minimizes noise or radio interference as much as possible.

R&D on various technical modules, which are necessary for rendering a prototype modem, has been carried out recently. Among several technical modules developed, below is one of our test results, especially for proving that the prototype modem is interoperable with DVB-S2X SF standard.

-. Purpose : To confirm successful extraction of DVB-S2X SF

-. Evaluation method : Verification by implementing DVB-S2X SF via RTL (Register Transfer Logic) simulator on demodulator of the modem.

RTL simulator configuration environment was based on C-simulator, whose implementation result corresponding to the FPGA code were verified.

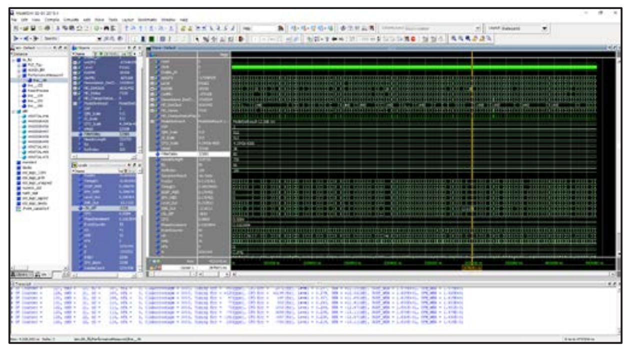
Figure 8. Example verified via analytic simulation

Below shows that, SOSF (Start Of SF) has been transmitted and received successfully, which constitutes the forefront part in SF, displaying to be within SOSF_WER(word error rate).

SF Counter = 4, nMD = 0, nD = 4, nFA = 0, ClkAccrochage = 3003, Timing Err = 58[ppb], CFO Err = 153[Hz], Level = 0.250, SNR = -12.32[dB], SOSF_WER = 0.000E+00, SFH_WER = 0.000E+00

SF Counter = 5, nMD = 0, nD = 5, nFA = 0, ClkAccrochage = 3003, Timing Err = -43[ppb], CFO Err = -1325[Hz], Level = 0.271, SNR = -12.32[dB], SOSF_WER = 0.000E+00, SFH_WER = 0.000E+00

SF Counter = 6, nMD = 0, nD = 6, nFA = 0, ClkAccrochage = 3003, Timing Err = 98[ppb], CFO Err = -705[Hz], Level = 0.240, SNR = -12.94[dB], SOSF_WER = 0.000E+00, SFH_WER = 0.000E+00

SF Counter = 8, nMD = 1, nD = 7, nFA = 0, ClkAccrochage = 3003, Timing Err = 131[ppb], CFO Err = -1850[Hz], Level = 0.219, SNR = -13.11[dB], SOSF_WER = 1.250E-01, SFH_WER = 1.250E-01

Figure 9. SF via RTL simulation

Below Figure shows SFH (SF Header) performance in the channel setting environment. The performance result was obtained after converting C-Simulator to the integer type, and RTL code identical to the integer type operation result was developed. It means that the RTL performance result was also almost identical to the figure above i.e. Integer type performance has only about 0.3[dB] loss compared to real type performance. In addition, the performance result shows the performance below SFH WER = 1E-5@-9[dB], which corresponds to the quantitative target. It also shows that there is a performance margin of about 0.5[dB] compared to the target of the task.

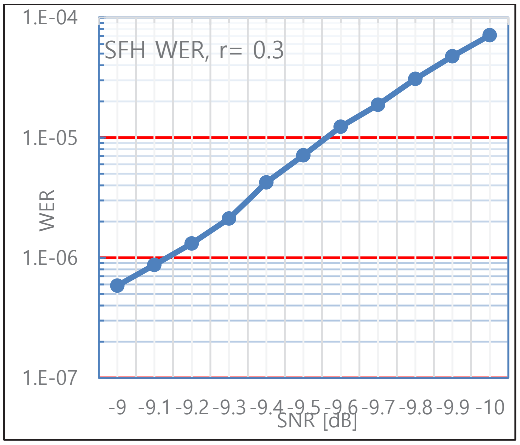

Figure 10. SFH Error Rate

We have several other technical modules tested but may be discussed in detail later via some other paper.

III. CONCLUSION

Firstly, current LEO operators like StarLink or OneWeb are providing their own technology-based beta services while some other like Lightspeed of Telesat already determined for DVB-S2X AnnexE based standard BH platform (For your information, Telesat is one of the most giant GEO operators unlike StarLink or OneWeb. Considering the enormous efficiency of BH described above, it is expected that most of those LEO operators will eventually adopt or gradually switch to BH technology, the ON-DEMAND resource allocation protocol.

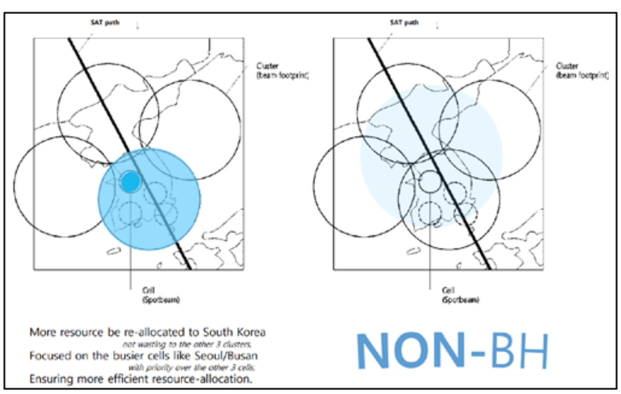

Figure 11. BH vs NON-BH scenario over Korea peninsula

Recently, patent has been filed in Korea on LEO BH, for instance, where more resource can be efficiently allocated to South Korean cluster, rather than wasting too much to the other (3) clusters, also focused on the busier cells like Seoul/Busan with more allocation of resource, than the other cells in the cluster, ensuring more efficient reallocation of resource, resulting in better LEO service quality as below.

Secondly, ETSI DVB-S2X AnnexE that has been released recently in 2021, presents various Waveform IDs of all Format 5, Format 6, and Format 7 enabling simultaneous support of LEO BH services of various requirements. In other words, if Format 5/6/7 are not supported simultaneously, it cannot be the optimal 6G platform because it cannot satisfy all applications of various requirements i.e. Optimal terrestrial/satellite integrated network which, not only improves the efficiency of satellite resources but also with minimized delay, can be rendered by developing a platform that supports all Formats 5/6/7 and then selectively activating or deactivating the optional Format(s) for each application, which then can support 4/5th Industry, with maximum efficiency and with minimum latency as well at the same time.

ACKNOWLEDGMENT

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