SATELLITE AND SPACE COMMUNICATIONS **SSC**
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The Satellite and Space Communications (SSC) Committee is a volunteer group actively involved in advancing satellite and space communication technologies within the IEEE. This committee is approved by the IEEE Communications Society and is governed by the constitution and bylaws of the IEEE as well as the other twenty-three Technical Committees in the Society. The committee belongs to the Technical Committee Clusters of Communication/Signal Processing (C/SP).

SATELLITE & SPACE

- JOIN US -

All conference attendees are welcome to join us in the SSC Committee meeting.

ONLINE MEETING URL:
https://zoom.us/j/98931735844?pwd=S2xUd1lKaFl2azRWbzZqZmhVME8xdz09

Time: Tuesday, May 16, 2023
12:00 AM - 13:00 PM EST (NEW YORK)

Future SSC Meeting

December 2023, Kuala Lumpur, Malaysia

ICC 2023 SSC Committee Activities:

Symposium on Selected Areas in Communications:

SAC-SSC1 *Tuesday, May 30, 11:30 - 13:00, Rome Time Zone*

SAC-SSC2 *Tuesday, May 30, 14:30 - 16:00, Rome Time Zone*

SAC-SSC3 *Tuesday, May 30, 16:30 - 18:00, Rome Time Zone*

SAC-SSC4 *Wednesday, May 31, 14:30 - 16:00, Rome Time Zone*

SAC-SSC5 *Wednesday, May 31, 16:30 - 17:15, Rome Time Zone*

SAC-SSC6 *Wednesday, May 31, 17:15 - 18:00, Rome Time Zone*

HOW TO JOIN SSC COMMITTEE AND MAILING LIST

If you like to join SSC Technical Committee: Please send your name and e-mail address to the SSC Secretary, optionally include your mail address, telephone and fax numbers.
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MESSAGE FROM THE CHAIR

Pascal Lorenz

I have served the SSC technical committee as chair for the past two years 2022-2023 starting in July 2022.

Since December 2022, the SSC TC has been put on probation during 6 months due to the lack of new information compared to three years ago 2020-2022. The SSC TC was in an inactive state and not able to have TC meetings until evaluated for recertification at the end of six months based on an updated report. We had working with the past chairs to improve the recertification file to receive a positive reply to schedule new TC meetings.

Due to serious personal problems, Prof. Mianxiong Dong step down this year from the position of vice-chair. Prof. Gunes Karabulut Kurt and I replaced Prof. Mianxiong Dong on the vice-chair position.

New elections (chair, vice-chair and secretary) will also be held this year to renew the Committee Officers for the period 2024-2025 and a call for candidates will be launched in the coming weeks.

I would like to take this opportunity to thank all the members of the community for their efforts and dedication in these difficult times.

SCANNING THE WORLD

Gunes Karabulut-Kurt

We have witnessed a record number of satellite launches thanks to reduced costs via recyclable launchers. Although these LEO satellites are still not a part of our connection experience, exciting new developments in the field will bring this technology closer to our daily lives, as the leading industry players aim to bridge the path-loss gap and bring the satellites to our smartphones. Cell-to-satellite connectivity promises a lucrative wireless broadband market that offers a sizeable opportunity that cannot be passed up. With the recent announcements from industry players, this is not solely a market dominated by start-ups, including Lynk, the first company to demonstrate the technical feasibility of sending a text message from space to an unmodified mobile phone.

An exciting development in the field is the newly announced Emergency SOS message service by Apple for iPhone 14 and iPhone 14 Pro, which will use Globalstar's satellites. This required a $450 million investment from Apple's Advanced Manufacturing Fund to provide critical enhancements to Globalstar's satellite network and ground stations. However, sending non-real-time low data rate messages is still far away from the consumer's connectivity expectations.

At the risk of being boring, I must remind the Friis equation, which indicates that the path loss increases as we increase the carrier frequency. However, when we need higher data rates, our only option is to increase the bandwidth by using higher carrier frequencies. So, how can we balance the link budget? The leading industry solution to this question lies in antenna sizes. In September, AST SpaceMobile's BlueWalker 3 satellite successfully deployed its 693-square-foot (approximately 64.4 square-meter) antenna, which was launched on SpaceX's Falcon 9 rocket. The company claims this is the largest-ever array deployed in low Earth orbit, with five more satellite launches planned for 2023.

AST SpaceMobile is not the only company thinking big in terms of antenna sizes. Elon Musk stated that Gen2 satellites will not only have significantly large antenna arrays but also support technology to accommodate the high Doppler shifts of LEO satellites to offer cell-to-satellite connectivity. The partnership announcement between T-Mobile and SpaceX also highlights the importance of the spectrum while increasing the connectivity objectives beyond mere messaging services. The integration of SpaceX satellites T-Mobile's mid-band PCS spectrum is planned for 2023, with ambitious cell rates of 2-4 Mbps. Of course, these rates may not offer any substitute for urban connections for the data rate-hungry consumers; however, they imply the end of the "dead zones" and extend connectivity beyond safety applications. The open call of worldwide reciprocal roaming from T-Mobile highlights the international importance of cell-to-satellite connectivity. Overall, it is clear that exciting times are ahead. But we are still yet to see whether the disruption will be close to the ones made by the introduction of GSM or iPhone.

FORTHCOMING GLOBECOM AND ICC CONFERENCES

GLOBECOM 2023

4-8 December 2023 // Kuala Lumpur, Malaysia

http://globecom2023.ieee-globecom.org/

IEEE GLOBECOM - IEEE Global Communications Conference (GLOBECOM) is one of the IEEE Communications Society's two flagship conferences dedicated to driving innovation in nearly every aspect of communications. Each year, more than 2,900 scientific researchers and their management submit proposals for

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program sessions to be held at the annual conference. After extensive peer review, the best of the proposals are selected for the conference program, which includes technical papers, tutorials, workshops and industry sessions designed specifically to advance technologies, systems and infrastructure that are continuing to reshape the world and provide all users with access to an unprecedented spectrum of high-speed, seamless and cost-effective global telecommunications services.

ICC 2023
28 May – 01 June 2023, Rome, Italy
http://icc2023.ieee-icc.org/

The International Conference on Communications (ICC) is one of the two flagship conferences of the IEEE Communications Society, together with IEEE GLOBECOM. Each year the ICC conference attracts about 2-3000 submitted scientific papers, a technical program committee involving about 1500 experts provides more than 10000 reviews, the conference being finally attended by 1500 - 2000 professionals from all around the world. IEEE ICC is therefore one of the most significant scientific events of the networking and communications community, a must-attend forum for both industrials and academics working in this area. IEEE ICC 2023 - Featuring the latest developments in telecommunications from a technical perspective.

CONFERENCES CALENDAR

CONFERENCE	DATE & LOCATION	INFORMATION
ITC 2023 35th International Teletraffic Congress	3 - 5 October 2023, Turin, Italy	https://itc35.itc-conference.org/ /
ICL-GNSS 2023 International Conference on Localization and GNSS	6-8 June 2023, Castellon, Spain	https://events.tuni.fi/icl-gnss2023/
VTC-Spring 2023 2023 IEEE Vehicular Technology Conference (VTC-Spring)	20-23 June 2023, Florence, Italy	https://events.vtsociety.org/vtc2023-spring/

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SSC Newsletter

PERSPECTIVE ARTICLE *December 2023*

Distributed satellite phased arrays for direct-to-cell connectivity

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Abstract - **The direct connectivity between satellites and common mobile terrestrial user equipment (UE), e.g. smartphones, represents an attractive and essential feature for future non-terrestrial networks. The industry is going in two different directions: large satellite apertures and limited-size constellations or limited satellite apertures and large-size constellations. In this dynamic context, distributed satellite phased antenna arrays represent an innovative and promising approach. This perspective article provides insight into the opportunities and a discussion of the potential research challenges for the feasibility of the proposed approach.**

Introduction

The next generation of communication networks, the 6G, is envisioned as a seamless integration of multiple network layers. Non-terrestrial networks, and in particular the satellite component, play an important role in this context since they are essential to complement the terrestrial coverage and provide ubiquitous connectivity. Although geostationary very high throughput satellites (GEO VHTS) are nowadays advanced systems with massive capabilities, they cannot fulfill the low-latency requirement of several 6G applications due to the large distance to the earth's surface. For this reason, low-earth orbit (LEO) satellites are receiving huge attention from the scientific community, standardization bodies, and industry. LEO satellites can provide reduced latency, thanks to the reduced distance to the earth's surface, but they bring several drawbacks, most importantly, a large constellation of satellites is required to assure global coverage.

The most interesting use of LEO constellations is to provide direct connectivity to terrestrial terminals. In the literature, the term direct connectivity addresses two main scenarios depending on the considered macro-category of the user terminals. The first type of direct connectivity considers very small aperture terminals (VSATs). A VSAT can be a parabolic dish of around 60cm in diameter, similar to GEO satellite terminals, but with a motorized system to track the LEO satellites. VSATs can also be phased antenna arrays able to electronically steer the main beam and track the LEO satellite. These terminals have good performance in terms of power and antenna capabilities, hence, they can use high frequency (mainly Ku and Ka bands) and benefit from large available bandwidth. Famous examples of operational/planned constellations for VSATs are Starlink (SpaceX), OneWeb, and Project Kuiper (Amazon). The second type of direct connectivity mainly considers common terrestrial user equipment (UE) and is henceforth referred to as direct-to-cell connectivity. These terminals are for example common smartphones characterized by low power and low antenna performance that can work with typical terrestrial distances but not with satellite ones. Therefore, the components of the communication system have to be improved. UE can only have little performance improvements for several reasons. Lower frequency bands (UHF, L, and S bands) reduce the channel impairments, such as free space path loss and atmospheric attenuation, but it is not enough to meet the objective. Therefore, the link budget can only be closed if the payload is equipped with a sufficiently large antenna aperture and/or the power is increased. Even in this case, there are famous examples from the industry, such as the AST SpaceMobile and Link Global satellites. These are two opposed approaches to the same final goal. The AST's plans consider a constellation of around 170 satellites with a massive aperture of around 128m^2 while Link Global's plans consider a mega constellation of around 5110 satellites with an aperture of around 4m^2 [1].

In this dynamic context, the Institute of Information Technology at the University of Bundeswehr Munich is investigating the potential benefits of distributed satellite systems for direct-to-cell connectivity. In particular, the aim is to evaluate a combination of multi-satellite architectures, swarm, and fractionated systems to create a distributed satellite phased array capable of replacing a single monolithic satellite in a LEO constellation. This perspective article presents the main opportunities and challenges that distributed satellite phased arrays introduce in the use case of direct-to-cell connectivity.

Distributed satellite phased arrays

Distributed satellite phased arrays are based on two main concepts, phased arrays, and distributed satellite systems. A phased array is a group of antenna elements connected via internal circuits and organized in a defined geometry, capable of changing the shape and direction of the radiation pattern without physically moving the antenna. The array elements are usually spaced about half the wavelength apart and transmit a phase-shifted version of the same signal. Phase shifts are calculated to provide constructive interference in the desired direction. The resulting radiation pattern offers better gain, directivity, and performance in a given direction than the single-element radiation pattern. On the other hand, a distributed satellite system (DSS) is composed of multiple satellites that are coordinated with each other to achieve a common goal. In the context of DSS, the satellite swarm refers to a configuration where a multitude of identical and autonomous satellites can achieve a common goal with their common behavior. The swarm configuration is also closely related to other terms, such as fractionated systems and Formation Flying (FF). In fractionated systems, the different satellites of the same distributed system have different functions, while the term Formation Flying refers to the problem of maintaining a desired separation, orientation, or relative position between satellites belonging to the same multi-satellite configuration.

In distributed satellite phased arrays each antenna element of the phased array is installed on a different satellite platform. The satellite platforms are organized in hybrid swarm/fractionated DSS formation. One or more satellites in the formation have enhanced capabilities, called the leader(s) or chief(s), while the other satellites are called followers or deputies. The satellites of the formation have an average inter-element distance on the order of ten times the wavelength. From the practical point of view, a distributed satellite phased array is composed of several small and lightweight satellites, e.g. CubeSats, equipped with a commercial patch antenna. The satellites can be organized in a free-flying formation (i.e., wireless connected) or a tethered formation (i.e., wired connected).

Distributed satellite phased arrays can bring several opportunities in the case of direct-to-cell use. Firstly, there is an advantage in terms of total antenna performance. Increasing the inter-element distance between the elements of the formation creates a large virtual aperture with a drastic reduction of the antenna elements. By carefully designing the geometry of the formation, the large virtual aperture generates a main lobe with higher gain and reduced half-power beam width compared to a conventional phased array with the same number of elements. Secondly, there is a twofold cost reduction opportunity. Conventional monolithic satellites have a unique design and production chain, whereas distributed satellite phased arrays are based on CubeSats and commercial off-the-shelf products that can be easily assembled. This can lead to reduced production costs. Furthermore, a CubeSat platform can integrate all components, including solar panels, in a lightweight cubic shape. Therefore, CubeSats can reduce the total weight and can be flexibly arranged in the rocket for launch, resulting in reduced launch costs. Finally, distributed satellite phased arrays inherit the advantages of distributed systems. In particular, the workload distribution on multiple elements makes the system fault-tolerant: a failure of single or multiple elements leads to a graceful performance degradation but not to an interruption of service. Distributed systems also introduce scalability: the performance of distributed satellite phased arrays can be improved by adding more elements to the formation.

Distributed satellite phased arrays appear to be a key element to realize large virtual apertures and a promising solution to reduce the design and launch costs of satellite systems. The advantages of a distributed approach for direct-to-cell connectivity are also recognized in the AST SpaceMobile patent from [2].

Research challenges

Despite the benefits, distributed satellite phased arrays present several difficult challenges to deal with and most of them are still unexplored for communication purposes [3].

Geometry design

Conventional phased arrays mainly use planar geometries, such as rectangular or circular, and an interelement distance of about half the wavelength. When the inter-element distance increases the beam pattern of the phased array suffers from grating lobes. Grating lobes are lobes having an amount of energy comparable to the main lobe but in unwanted directions. The grating lobe problem has been studied in the literature, and the common idea to mitigate its effect relies on the interruption of the periodic element distance present in conventional geometries. Therefore, the geometry design of distributed satellite phased arrays is a crucial aspect. 2D geometries based on the Fermat spiral provide good results [4], but 3D geometries could lead to further improvements.

Formation Flying

A distributed satellite phased array, organized according to an optimized geometry, must be kept stable during the flight around the Earth. However, various effects like Earth's oblateness, atmospheric drag, and solar radiation pressure significantly influence the positions of the elements, making periodic orbit corrections necessary to maintain stability. Promising studies on Formation Flying, electric propulsion, electromagnetic forces, and the increasing effort in space flight demonstrations [5] suggest the feasibility of distributed satellite phased arrays in free-flying formations in the near future.

Synchronization

A large degradation of the performance when the optimized geometry varies from the perfect one is not expected, since the grating lobes are mitigated by breaking the periodicity of regular geometries. Most importantly, the phase differences between the satellites and a common reference point must be estimated with a certain degree of accuracy, and the phase shifts updated accordingly. For this reason, synchronization is one of the most important aspects of distributed satellite phased arrays.

The scientific literature offers multiple solutions to approach the problem [6]. According to a preliminary analysis, a synchronization process based on open-loop strategies, RF, and differential GPS technologies could be sufficient to achieve the required level of coordination.

Beamforming optimization

The beamforming optimization of a distributed satellite phased array is important in two aspects. Firstly, residual synchronization errors and other sources of imperfection could degrade the expected level of performance. Therefore, robust beamforming algorithms must be developed to limit performance degradation to an acceptable level. Secondly, the full potential of distributed satellite phased arrays can only be achieved by considering the generation of multiple beams. There is a large research background that can be used in this context and the recent literature on the massive MIMO technique in LEO satellite systems [7] opens up interesting developments.

System design aspects

In addition to the research challenges described above, several design aspects influence the level of complexity of the entire system, such as the division of tasks between the leader(s) and followers of the same distributed satellite phased array, or the division of tasks between space and ground sections. Furthermore, it must be emphasized that synchronization and Formation Flying are stringent requirement mainly for free-flying systems. Systems with a wired connection between satellites (tethered) drastically reduce these requirements. Tethered systems could also use very small satellite platforms based on the "satellite on a chip" or "satellite on a printed circuit board" concept to further reduce production and launch costs.

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