News & views

The 6G switch that spares scientific services

Janise McNair

Next-generation wireless services will demand massive increases in data traffic, requiring access to signals at higher frequencies than are presently used. This would disrupt scientific research, but a savvy sharing protocol offers a fix.

Smartphones are rarely used for talking. Data services are taking over the spectrum of frequencies reserved for wireless communications, and as the sixth-generation (6G) global network appears on the horizon, the demand for such services will require 6G allocations to be extended to higher frequencies than are used at present. In 2019, the US Federal Communications Commission (FCC) approved the commercial use of frequencies exceeding 100 gigahertz (1 GHz is 10^9 Hz), allowing the 6G extension (see go.nature.com/3kzs2sd). But such activity would interfere with passive signals that are used for scientific services, such as radio astronomy, space research and satellite systems. Writing in *Communications Engineering*, Polese *et al.*[1] propose a way for active 6G applications to coexist with these passive services while using the same spectrum.

4G wireless traffic consists mainly of texts, social-media videos and live-streaming services. As well as offering the same services as 4G, the next generation, 5G, which is expected to represent 10% of all global mobile connections by 2023 (see go.nature.com/3yvqnwb), supports machine-to-machine data applications. These include the Internet of Things (the network of everyday objects that have sensors, software and other communications technologies), the Industrial Internet of Things (a network of smart sensors and actuators that can enhance manufacturing and industrial processes), as well as vehicle-to-vehicle and vehicle-to-Internet connections.

Both 4G and 5G have been allocated frequency bands up to 6 GHz (Fig. 1a), although increased capacity is already needed by 5G, which will have access to frequency bands between 24.2 and 52.6 GHz in the future[2]. Frequencies in this range are known as mmWave bands, because their wavelengths fall between 10 millimetres (30 GHz) and one millimetre (300 GHz).

6G requires an even larger spectrum allocation, because planned 6G services will include ultrahigh-definition video and a variety of augmented and virtual-reality services for gaming and applications related to the metaverse (a collective virtual space). The spectrum plan for 6G services will include a 'high-occupancy lane' to move data rapidly, and a 'backhaul network', which acts as an exit lane to offload data from the wireless information superhighway to the wired network. For example, when many users are transmitting data through the same mobile-phone tower, the network can automatically transfer connections involving stationary users to a nearby static wireless router, enabling more mobile users to access the tower.

Frequency allocations above 100 GHz are conceptually separated into subterahertz (1 THz is 10^{12} Hz) bands of 90 to 300 GHz and terahertz bands of 300 GHz to 3 THz. These bands use narrow-beam antennas, which increase the strength of the signal in the direction in which they are focused, while reducing it in other directions. This minimizes interference between signals and enhances security by reducing the opportunity for eavesdropping[3,4]. The pulse durations are short, which also tightens the security of communications, and the radiation is non-ionizing, which means that it is safe for human use.

The 6G backhaul network requires short bursts of radiation across wide swathes of the frequency spectrum (tens of gigahertz) in the subterahertz and terahertz ranges. But accessing large chunks of bandwidth at these frequencies would disturb scientific research activities, such as those carried out by NASA's Aura, a satellite tasked with studying Earth's ozone, air quality and climate. One method for satisfying both sets of users – to accommodate active 6G offloading without disrupting scientific signals – is known as dynamic spectrum sharing. This involves sensing whether sections of the spectrum are currently being used, and sharing the unused frequencies in a dynamic way[5].

In spectrum-sharing schemes, the main users of the spectrum (in this case, passive scientific users) have exclusive access to the spectrum, whereas secondary (6G) users can transmit and receive data only through frequencies that are left temporarily unoccupied by the passive signal – if only for a fraction of a second. Knowledge of a passive user's transmission pattern can therefore be used to form a schedule on which to execute active transmissions. But if such patterns are not available, sharing the spectrum requires the occupied (or unoccupied) status of frequencies to be sensed dynamically: the active user must monitor the behaviour of the passive signal to detect when
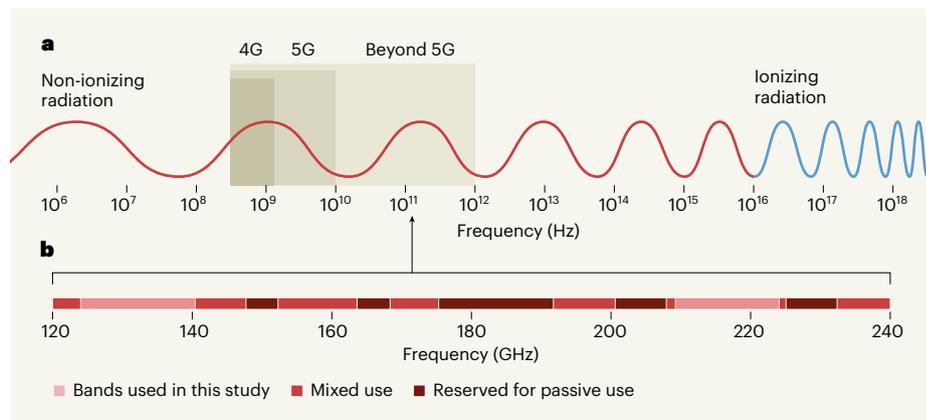

Figure 1 | A dynamic strategy for high-frequency spectrum sharing. a, Sixth-generation (6G) wireless networks will need access to frequencies higher than those used by 4G and 5G, but still in the range of non-ionizing frequencies that are safe for human use. However, transmitting and receiving data at frequencies higher than 100 GHz (1 GHz is 10^9 Hz) disrupts passive scientific signals, such as those used for radio astronomy research. **b**, Polese *et al.*[1] demonstrated a spectrum-sharing scheme in this range using an active 6G user and NASA's Aura satellite as an example. The experiment senses the satellite and avoids interference by switching the active user between a lower frequency band at 123.5–140 GHz and an upper band at 210–225 GHz. These bands fall within the spectrum allocated for mixed use, which includes passive scientific services and active mobile services. The Aura sensors operate at frequencies higher than that of the upper band, but signals transmitted by the active user could extend up to 240 GHz, thus potentially interfering with the satellite, and necessitating a switch to the lower band.

frequencies are unoccupied, actively transmit during this period, and cease transmission when the passive signal returns.

Spectrum-sensing methods include techniques for detecting the energy or special features of a signal; those that match the signal to a known template; and those that detect the degree to which two signals are in step with each other[6]. The outcome of these methods is evaluated by calculating the detection probability (the probability that an occupied spectrum is correctly detected) and the false-alarm probability (the probability that an idle spectrum is incorrectly identified as being occupied). In cooperative spectrum sensing, multiple users make independent sensing measurements that are then collected and processed at a single node to better calculate these probabilities using the increased information.

However, although such techniques are well established, implementing the hardware for spectrum-sharing systems isn't easy. Furthermore, few researchers have attempted this at subterahertz frequencies. Polese *et al.* tackled this problem by performing spectrum-sharing experiments between a passive scientific user, the Aura satellite, and an active 6G user transmitting and receiving data at frequencies above 100 GHz. They achieved this by tracking Aura's orbits and assuming that the 6G-network activity would interfere with the satellite when the orbit was within the line of sight of the 6G user on the ground. Line-of-sight alignment therefore precluded active use, but non-alignment indicated that the spectrum was unoccupied and available. The authors obtained a licence from the FCC to implement the hardware for this scheme, and performed their experiments in an urban environment, with a transmitter and a receiver on the rooftops of adjacent buildings in Boston, Massachusetts.

Their approach involves a dual-band system, in which the 6G user's activity is dynamically switched between a lower band, at frequencies of 123.5–140 GHz, and an upper band, at frequencies of 210–225 GHz (Fig. 1b). The team integrated the hardware with programmable controls that switch the 6G active user between bands automatically and rapidly, to avoid interfering with the passive signal.

The method proved successful in tracking a single satellite with known orbital patterns. However, scaling it up to many passive and active users might be difficult. Line-of-sight tracking for multiple satellites is more complex than it is for one satellite, which complicates the task of determining when and where on the spectrum active 6G transmission can be safely undertaken.

The challenge of making new lanes for the ever-expanding wireless-network traffic remains a moving target. But Polese and colleagues have shown that spectrum sharing is a viable solution to the problem of active users interfering with passive signals — a

welcome and timely development now that spectrum allocations above 100 GHz are being released. The approach will no doubt be further strengthened by emerging sensing techniques based on cooperative strategies and machine learning. These provide high detection accuracy using low-complexity algorithms, and can be tailored to suit different situations and users[7,8].

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Palaeontology

The fossil riddle of *Palaeospondylus*

Jorge Mondéjar Fernández & Philippe Janvier

For more than a century, scientists have pondered over mysterious fossils of an aquatic vertebrate, and argued about the type of creature this species represents. Newly analysed specimens might help to solve this puzzle. **See p.109**

If you look for fossils at the celebrated Achanarras Quarry in the Highlands of Scotland, you might stumble upon a small, fish-like animal, no more than a few centimetres long and suggestive of a tadpole, called *Palaeospondylus gunni*. This creature, which is the most common fossil vertebrate in the lake deposits there, dates to about 385 million years ago (the Middle Devonian period). It is found hardly anywhere else, and is probably one of the most mysterious fossil vertebrates ever uncovered. Since its discovery[1] in 1890, because of its unusual mix of characteristics in terms of its shape, small size, elongated body and apparent lack of paired fins, *Palaeospondylus* has been interpreted in various ways and provoked many heated debates. On page 109, Hirasawa *et al.*[2] report compelling evidence that might be useful in efforts to solve the *Palaeospondylus* riddle.

Palaeospondylus was initially interpreted as being some kind of jawless fish (belonging in a grouping called agnathans, which includes living lampreys and hagfishes)[1], possibly one foreshadowing the origin of jawed vertebrates (termed gnathostomes). As the palaeontologist Adolphe Kemna[3] put it: "it is a real monster. It is merely an intermediate animal, that still and already displays the characters of the two groups [the agnathans and gnathostomes], which it links ... it is the 'Archaeopteryx' of the gnathostomes!" (The *Archaeopteryx* fossil shed light on bird evolution from non-avian

dinosaurs.) Indeed, the jawless interpretation of *Palaeospondylus* had many supporters, although others saw resemblances with gnathostomes, such as chondrichthyans (cartilaginous fishes, including sharks), placoderms (extinct armoured jawed vertebrates) or even dipnoans (lungfishes)[4].

Represented by thousands of specimens, *Palaeospondylus* has been the subject of numerous studies using different, and sometimes groundbreaking, methods[5–7], which have confirmed or refuted the various proposed placements of this species on the evolutionary tree over the years. As such, *Palaeospondylus* has been attributed to almost every major vertebrate group, and was even considered to belong to its own new group[5]. How can we explain these disparate attributions for such a relatively well-characterized fossil?

The difficulty in interpreting *Palaeospondylus* lies in its peculiar preservation pattern. Its delicate skeleton was assumed to be made entirely of cartilage, thus constituting a true internal skeleton (termed an endoskeleton). However, there are no indications of dermal bones, which form an exoskeleton, and thus no ornamentation or teeth, which are generally used to assign fossil fishes on the evolutionary tree. This unusual absence of an exoskeleton suggested that *Palaeospondylus* might be a kind of larva or juvenile of any of the aforementioned fish groups, preserved early in development, before the exoskeleton formed[4].