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Abstract (Document Summary)

How humans harness electromagnetic waves - and specifically those in the radio-frequency part of the spectrum - has become so important that old and new ways of thinking are now lining up for a tense confrontation that will affect numerous businesses and billions of consumers. The old mindset, supported by over a century of technological experience and 70 years of regulatory habit, views spectrum - the range of frequencies, or wavelengths, at which electromagnetic waves vibrate - as a scarce resource that must be allocated by governments or bought and sold like property. The new school, pointing to cutting-edge technologies, says that spectrum is by nature abundant and that allocating, buying or selling parts of it will one day seem as illogical as, say, apportioning or selling sound waves to people who would like to have a conversation.

Full Text (2819 words)

Governments and industries are bracing themselves for the possibility that radio interference will become a thing of the past

MOST people do not worry much about physics or politics when, for example, they look at the colours of a rainbow. Nor do they pause much when they use a remote control for their TV set, talk on a mobile phone, listen to the radio, cook food in their microwave oven, open their car door from a distance, or surf the internet without wires. Yet these are all phenomena of electromagnetic radiation. How humans harness electromagnetic waves--and specifically those in the radio-frequency part of the **spectrum**--has become so important that old and new ways of thinking are now lining up for a tense confrontation that will affect numerous businesses and billions of consumers.

The old mindset, supported by over a century of technological experience and 70 years of regulatory habit, views **spectrum**--the range of frequencies, or wavelengths, at which electromagnetic waves vibrate--as a scarce resource that must be allocated by governments or bought and sold like property. The new school, pointing to cutting-edge technologies, says that **spectrum** is by nature abundant and that allocating, buying or selling parts of it will one day seem as illogical as, say, apportioning or selling sound waves to people who would like to have a conversation.

The traditional mindsets were colourfully on display this week when full details were announced of a complicated **spectrum** swap arranged by America's telecom and media regulator, the Federal Communications Commission (FCC). First announced on July 8th, the swap gave

Nextel, America's sixth-largest mobile-phone carrier, new slices of **spectrum** in return for vacating other bands where it was causing interference with the radios of firemen, police and hospital workers. If it wins final approval, the deal will cost Nextel $3.25 billion. It follows years of what Michael Powell, the FCC's chairman, called "ruthless lobbying". Nextel's rivals threaten to contest the decision, screaming that Nextel got a windfall of public property. Verizon Wireless, America's largest carrier, recently bought another piece of **spectrum**, in New York, for $930m.

A glimpse of the new mindsets, by contrast, can be had in any Starbucks coffee-shop where patrons connect to the internet through Wi-Fi, a technical standard (officially called 802.11) that does not have a government licence but operates in "unlicensed" bands of **spectrum** in the 2.4GHz or 5.8GHz range. These are bands which governments have deliberately set aside as, in effect, an experiment for new technologies such as Wi-Fi. Almost anything goes in these bands, and any interference--between Wi-Fi base-stations and cordless phones, say--is for vendors, not the government, to sort out.

On one side, therefore, are notions of radio frequencies as scarce resources that can be used by only one transmitter at a time and are worth lobbying and paying billions for; on the other side is the idea that any number of transmitters and receivers can peacefully co-exist on the airwaves and that **spectrum** should therefore be open to all--not individual property, but rather a commons. To understand this debate, one must look back at history; to understand its importance, at economics.

Slicing up the airwaves

For decades after Guglielmo Marconi invented the radio in 1897, the only way to send multiple radio signals at the same time was by transmitting them at different wavelengths. Radio receivers were dumb devices--copper coils, essentially--and if two signals came in on the same wavelength, the result was noise. So when America passed the Radio Act in 1927 and the Communications Act in 1934, and other countries followed with similar legislation, the reigning wisdom was that governments had to chop up the radio-frequency **spectrum** and give exclusive privileges in each band to avoid chaos: radio required central planning.

The next major change in this understanding came in 1959, when Ronald Coase, later a Nobel laureate in economics, argued that the market was far better than governments at allocating the scarce resource of electromagnetic **spectrum**, and that auctioning **spectrum** to the highest bidder was therefore superior to simply giving licences away. This fitted well with the Zeitgeist of the following decades, when economists such as Milton Friedman and Friedrich von Hayek won Nobel prizes for similar arguments in other areas of life. Starting in 1995, governments in America and Europe began selling **spectrum** by auction. Telecoms companies were the biggest buyers, mortgaging their balance sheets to get airwaves for a new generation of cellular services.

The underlying assumptions about the physics of electromagnetism had not changed, however. Devices were still assumed to be dumb, interference a fact of life and exclusive-usage rights a necessity. The only change is that today most governments run mixed regimes, doling out some licences for free and auctioning others. Not all that mixed, however: auctions account for only 2% of the radio-frequency **spectrum** (up to 300GHz or so) in America. Central planning, in other words, still accounts for 98% of the usable airwaves. Most of the **spectrum** is given to television broadcasting, military communications and other forms of dedicated content.

This dispensation represents a huge loss to society. James Snider at the New America Foundation, a think-tank in Washington, DC, estimates that America's airwaves would have been worth $771 billion in 2001 (when he last did the sums) if every licensee were to use his bandwidth for the service in most demand by the public. But licensees do not do this, or cannot because of regulations. This means that about half of the total value of the airwaves is wasted on uneconomic uses--on extra broadcasting capacity, say, instead of more cellular communications.

It would be bad enough if most of the **spectrum** were being wasted on the wrong uses; in fact, much of it is not being used at all. According to one study, only four of 18 ultra-high frequency TV channels in urban Washington, DC, were actually in use when the study was done. In rural areas, the "white spaces" of fallow **spectrum** are even more vast. An official at America's National Telecommunications and Information Administration, which manages all the **spectrum** used by the federal government (as opposed to the FCC, which regulates all other uses), once estimated that 95% of the government's **spectrum** is not being used at any given time.

Commons, minus the tragedy

The sheer waste of this system--the "opportunity cost" of services and technologies not offered because entrenched interests are squatting on the **spectrum**--is behind the third major intellectual current, after central planning and property rights, in recent thinking about **spectrum**. Starting in the 1980s and gathering steam in the 1990s, there have been calls for "open **spectrum**", or a **spectrum** commons. These initially met with scepticism, since economists and most other people are familiar with "the tragedy of the commons"--the idea that a scarce resource will be inefficiently over-exploited (as in the case of over-fishing, the classic instance). For sceptics, the same fate would await the airwaves.

But this is wrong, says Kevin **Werbach** at the University of Pennsylvania's Wharton business school and founder of Supernova Group, a consultancy. He argues that the assumption that public sharing of **spectrum** would lead to chaos presumes that **spectrum** is scarce; but this reflects a flawed understanding of the physics of electromagnetism. A common myth about electromagnetic waves is that they bounce off one another if they meet. They do not. Instead, they travel onwards through other waves forever (even though they eventually attenuate to the point where they become undetectable). Radio interference, in other words, is not a physical phenomenon, but always and only a technological problem, the result of dumb radios and dumb antennae mixing the waves up after receiving them.

If devices are smart enough to distinguish between signals, says Mr **Werbach**, **spectrum** suddenly reveals itself to be not scarce, but abundant. Mr **Werbach** draws an analogy to acoustics. A well-attended cocktail party has a din of many voices speaking at once and on similar frequencies. But it is still possible for party-goers to have conversations and pick out individual voices--ie, sound waves--from the din, because our brains are equipped with powerful software for this task. There is no limitation in the **spectrum** of sound waves, only in the refinement of the human ear. The same can be true in the electromagnetic **spectrum**.

There are four broad categories of new technologies that could make this idea a reality. The first is called "spread **spectrum**", or "wideband". As both names imply, this is a way of spreading an electromagnetic signal across wide bands of frequencies at low power, instead of booming a high-power wave through a narrow band. Wi-Fi is one good example of wideband technology--the large range of frequencies and the low power allow it to co-exist with cordless phones and other devices. Hopes are highest, however, for a new technology called "ultra-wideband", which will communicate by whispering its signals so softly across the frequency bands of other, higher-power transmitters, such as broadcasters, that these will not even notice the presence of another signal.

Another approach is to use "smart" antennae. These are systems of multiple antennae that can "aim" a signal in a particular direction (instead of radiating it out indiscriminately) or pick out a particular signal from background noise by calculating the wave's angle of arrival (for example, from a satellite instead of a source on the ground).

A third technology is "mesh networking". In a mesh, each receiver of a signal also re-transmits it. Every meshed laptop computer, for instance, in effect becomes a node or router on its network. This has three advantages. One is that, as with spread **spectrum**, signals can be sent at very low power, since they only have to travel to the next user's node, which will be hundreds of metres, instead of kilometres, away. Another is that each newcomer to the network not only uses, but also adds, capacity. A third is that the network will be robust, since traffic can be re-routed easily if nodes fail, the approach already taken by the internet.

Open-**spectrum** enthusiasts are most excited, however, about the day when radios become software-powered computers, or so-called "cognitive radios". This would end the limitations of dumb radios. "Moore's law meets Marconi's transmitter," says Kevin Kahn, research boss for communications at Intel, the world's largest semiconductor-maker, referring to the prediction, so far correct, by Gordon Moore, one of Intel's founders, that the number of transistors on a chip doubles every 18 months. Radios would double their intelligence every year and a half, in other words. They could learn to hop around on the **spectrum** to find quiet bands for transmission, to encode digital information in new wave forms, or to analyse incoming noise and pick out only the relevant signal. "Communication is no longer a matter of frequency, but of computation," says Mr Kahn. In effect, cognitive radios would play the part of human brains at noisy cocktail parties.

Back in the real world

A lot of breakthroughs still need to happen before these technologies become widespread and reliable. Enthusiasts who predicted that there would be Wi-Fi transmitters in every street lamp have backtracked. "Hotspots" are mushrooming, and cities from Montpelier, Vermont, to Hamburg, Germany, are now stringing networks of them into larger "hot zones" that blanket downtown areas and entire neighbourhoods with high-speed internet access, but this seems to be an option only for dense urban areas. Mesh networks, too, are still rare. Police and firemen and other city employees in Medford, Oregon, have this year started using a mesh network to connect to the internet while on the road, but very few ordinary consumers are meshers. Cognitive radios are still in the lab.

Incumbent licence-holders--and above all the telecoms firms that have paid billions in **spectrum** auctions--naturally use the immaturity of these technologies as their prime argument against a headlong rush away from the property model and towards a commons approach. "Unlicensed **spectrum** is sounding like crack cocaine: the ultimate high that solves all your problems," says Brian Fontes, a lobbyist who works for Cingular, America's second-largest mobile-phone company (and the largest once its acquisition of AT&T Wireless, a rival, is complete). But, "prove that you're not going to interfere; I mean prove it, don't just say it," he insists.

The fact is, Mr Fontes says, that there is still no way to guarantee quality of service in the unlicensed bands. Yet guarantees are needed, if only for security. Such reminders are in the economic interests of Mr Fontes's industry, but that does not make them wrong. Regulators think it would be dangerous simply to embrace open **spectrum** and unleash a free-for-all. Rather, they see their task as managing **spectrum** so that it usage remains as efficient as technology allows.

There are several ways to do this without adding new unlicensed bands. One clear and obvious step is to allow "underlay". This is a way of transmitting signals in somebody else's licensed band, but without disturbing the licence-holder in any way--for the incumbent, a bit like having a bird sitting in your garden. This could help to fill in the huge white spaces of unused **spectrum**. It could also ease the politics, since it will not be easy to persuade powerful and long-standing licence-holders to vacate their bands. With underlay rights, says Vanu Bose, the boss of Vanu, a firm that designs software-powered radios, "the broadcasters don't even have to get off the **spectrum** they have now, because they don't use most of it."

Another good measure for regulators is to make licences more flexible. This is perhaps most urgent in Europe, where the European Commission currently requires telephone operators to use a technology called W-CDMA as they build third-generation (3G) mobile-phone networks. In 2000 the carriers paid more than euro100 billion (then $125 billion) for these licences, and are only now rolling out services after experiencing technical flaws. Meanwhile, operators in South Korea, America and Japan have been able to launch 3G services using a rival technology, CDMA2000, that is more mature but is, in effect, banned in Europe. But licence flexibility needs to go even further. Ultimately, a mechanism for licence-holders to trade their rights on a secondary market, similar to a bond or commodity market, could lead to more efficient allocation.

Nonetheless, the share of unlicensed **spectrum** should rise over time in order to spur innovation. In America, where the FCC has been thinking about the potential of open **spectrum** since 1981, this idea is no longer controversial. Michael Powell, the FCC's chairman, has said that he would like to see himself more as a speed cop than as a real-estate agent, and makes clear his penchant for unlicensed bands. America's **spectrum** regulator essentially agrees: the National Telecommunications and Information Administration proposed on June 24th that both it and the FCC identify an additional 10MHz of **spectrum** for this purpose. The problem, in America as everywhere, is in the politics of choosing someone to evict.

A few pioneers profess indifference to the debate. Dewayne Hendricks, boss of Dandin Group, a wireless internet-access provider, does not care whether governments open up more **spectrum** because, "all the **spectrum** we need is already in play." He has already brought wireless internet to "tall and uncut" places from Tonga to Ulan Bator, and says he is now in talks in Armenia. Most industry participants, however, are keen for more open **spectrum**. One opportunity that will present itself in many countries is the migration from analogue to digital television, which will reduce the bandwidth needed for traditional free-to-air broadcasters.

The sweet and low down

This is promising because broadcasters inhabit the best kind of **spectrum**, the equivalent of beachfront property. The lower an electromagnetic wave's frequency the better it is at penetrating rain, trees and walls, which is why television and FM radio tend to work in the basement, but why Wi-Fi signals have trouble with walls. According to the New America Foundation, the 1% of frequencies below 3GHz are worth more than the other 99% of **spectrum** between 3GHz and 300GHz.

Even a sliver of new unlicensed **spectrum** in the very low frequencies could therefore make an enormous difference. It could, for example, make possible a cheap alternative to cable and digital-subscriber line modems (for which roads have to be dug up and trees uprooted) in delivering high-speed internet access across "the last mile" to the consumer.

"Amazing things have been done with Wi-Fi in garbage **spectrum**," says Tren Griffin, who is in charge of **spectrum** matters at Microsoft. "The pregnant question is: what if we took a tiny amount of good **spectrum** and repurposed it?" It might at last become feasible and economic to begin bridging the world's digital divide. If low-frequency **spectrum** became free for innovators, then business plans to bring connectivity to villages in India and China, as well as rural Montana, would soon follow. Lives in many places could one day be richer thanks to vibrations in the air.