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Bridging Africa's Broadband Divide

HOW MALAWI AND SOUTH
AFRICA ARE REPURPOSING
UNUSED TV FREQUENCIES FOR
RURAL HIGH-SPEED INTERNET

AT MULANJE SECONDARY SCHOOL, in Malawi's verdant tea-growing district, something remarkable is happening: Students and teachers now have broadband access to the Internet for the first time, thanks to an over-the-air network that connects the school with a telecom provider in a nearby town. Installed last year, the network transmits signals over unused portions of the television spectrum—known as TV white spaces—from a high-gain antenna mounted atop the sturdy brick-and-stucco building to a radio tower owned by Malawi Telecommunications, 2.6 kilometers away. Inside the school, in a new computer lab, students check email, do homework, and hang out on social media, just like teenagers the world over. • At the network's launch in May 2015, Kondwani Nankhumwa, who was then Malawi's minister of information, tourism, and culture, listed the many ways in which the new broadband link would aid the community. Local residents, he said, “will be able to communicate to relatives who are working abroad. Small-holder growers will be

able to access the prices of crops on the global market. Tourists interested in visiting Mulanje Mountain will be able to book accommodations, transport, and tour guides.” What’s more, he predicted, the same TV white space technology could help lift Malawi’s Internet penetration from less than 10 percent today to around 70 percent by 2019.

It’s noteworthy that Malawi, one of the world’s least developed countries, is not only embracing this technology but also spearheading its development. One of us (Mikeka) oversaw the deployment at the school as well as an earlier trial in 2013, and his lab at the University of Malawi, in Zomba, has been developing low-cost components and software for use in such networks. The push for TV white space adoption is not just happening in Malawi: At last count, there were nine trials of this technology going on in eight African countries.

Being part of the global digital village requires a good fiber backbone and high-speed wireless. But these two key technologies are still uncommon in sub-Saharan Africa, where about 60 percent of the population lives in rural areas. (In Malawi, the figure is more like 85 percent.) For broadband Internet to make its way to the most remote parts of the continent, TV white space technology looks to be one of the most promising and most affordable approaches. After all, rural areas, although far removed from telecom infrastructure, enjoy a relatively uncluttered electromagnetic spectrum. So for sub-Saharan Africa, using TV frequencies to provide Internet access makes good sense.

Hundreds of millions of Africans now rely on their mobile phones for banking, trading, and generally staying informed and connected. A recent report from GSMA, an industry group representing mobile operators, reported 367 million

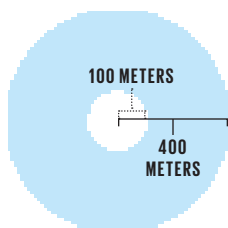
cellphone subscribers in sub-Saharan Africa in mid-2015. Yet when it comes to broadband Internet, much of the continent remains on the wrong side of the digital divide. Only 20 percent of African cellphone users have smartphones, and the vast majority of them live in large cities. In South Africa, the sub-Saharan country with the highest per capita gross domestic product, only 37 percent of households have any kind of Internet access, and in Malawi, just 6 percent do.

Even where it’s available, broadband is far too expensive for most people. In Malawi, mobile broadband typically costs more than US \$14 per 4 gigabytes of data per month—nearly 50 percent of the average per capita income. For a dedicated 1-megabit-per-second line, the fee is \$850 per month; compare that with the average price in Seoul, South Korea, of less than \$30 per month. Similarly steep rates can be found elsewhere in Africa.

Various approaches have been explored for deploying rural broadband in Africa, but none have been completely satisfying. A number of projects, for instance, have adapted and expanded Wi-Fi’s reach by using high-gain antennas and adding mesh capability to the radios; a mesh network relies on software to automatically route connections through the nearest radio. But Wi-Fi uses frequencies that are effectively line of sight and propagate poorly through foliage and buildings.

Exploiting unused TV spectrum has the potential to be a lot cheaper than Wi-Fi for rural areas. For the same amount of power, a TV white space signal can cover a far wider area than a higher-frequency Wi-Fi signal can, so you need fewer antennas and fewer base stations. Theoretical calculations show that a 600-megahertz TV white space signal has 16 times as much coverage as a 2.4-gigahertz Wi-Fi signal.

Some people have taken to calling TV white space technology “Super Wi-Fi” or “White-Fi,” but we find those terms misleading because the technology is very different. TV white space uses VHF and UHF frequencies that have been set aside primarily for television broadcasts but



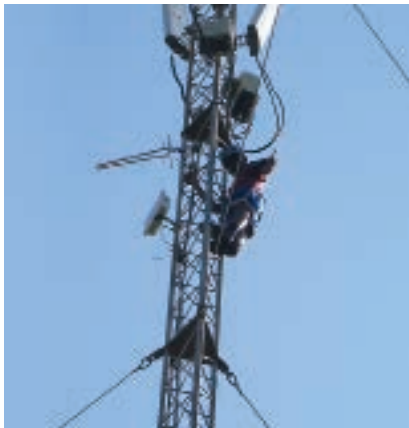
FAR AND WIDE:

Theoretical calculations show that for the same amount of power, a 600-megahertz TV white space signal can travel four times as far as a 2.4-gigahertz Wi-Fi signal and cover 16 times as much area.



are not in use in particular geographic regions or at specific times. The transition from analog to digital TV has opened up quite a bit of that spectrum. For TV white space networks, UHF is more attractive than VHF because its shorter wavelengths mean that smaller antennas can be used. The exact frequencies vary from country to country; in the United States, for instance, the allowed TV white space frequencies cover channels 2 through 51 except for channels 3, 4, and 37. And rural regions, especially those in sub-Saharan Africa, have no shortage of unused TV frequencies—sometimes the entire UHF and VHF bands are available.

To date, the main proponents of TV white spaces have been Japan, Singapore,



CLOCKWISE FROM TOP LEFT: STEVE SONG; CHOMORA MIKEKA (B); DANA JO PHOTOGRAPHY; GOOGLE

the United States, and the United Kingdom. In the past several years, hundreds of trials around the globe have used the technology to provide wireless broadband access. But Africa has far more available TV spectrum than any other part of the world and also the most to gain from using the technology.

When we began the project at the Mulanje school in 2015, we started by scanning the spectrum using an off-the-shelf spectrum analyzer—a \$120 RF Explorer made by Nuts About Nets, based in Bellevue, Wash. We ran the spectrum measurements through our own Linux shell scripts running on laptops or PCs. Our system captured data every 3 seconds, geotagging and time-stamping each entry, and

it then calculated the spectrum “occupancy.” A typical scan might indicate that out of the 28 UHF channels allocated to television stations in the region, just 7 were in use locally—which meant that three-quarters of the band was free. From those results, we developed a rule-based expert system that factors in Malawi’s TV white space regulations and automatically switches the TV white space radio (from the Ottawa company 6Harmonics) to an available channel.

For the earlier trial in 2013, in the university town of Zomba, we’d used radios from Carlson Wireless Technologies, based in Arcata, Calif. That project was a partnership between the International Center for Theoretical Physics (ICTP) in Trieste, Italy; the Malawi Communica-

ONLINE LEARNING: Schools in Mulanje, Malawi, and Cape Town, South Africa, now connect to the Internet through TV white space networks set up in 2013 and 2015. Clockwise from upper left: University of Malawi students show off UHF antennas; coauthor Mikeka climbs a radio tower; Mikeka and Jonathan Pinifolo of the Malawi Communications Regulatory Authority celebrate with students at Mulanje Secondary School; Mulanje students learn how to conduct spectrum scans; antennas at Cape Town’s Tygerberg Hospital send TV white space signals to 10 schools; Cape Town students now have access to educational websites, social media, and email.

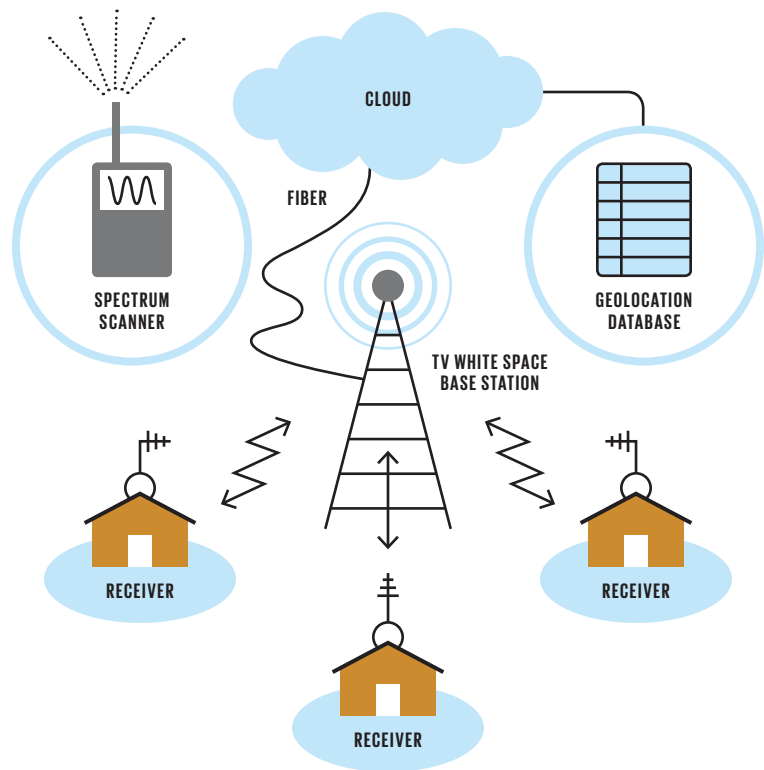
tions Regulatory Authority (MACRA); and the physics department of Chancellor College at the University of Malawi. The trial used wideband (470 to 790 MHz)

omnidirectional white space antennas placed on a radio tower near Chancellor College. The network included four sites, one of which was nearly 20 km away and set a record for the longest operational TV white space link. We're not sure yet how far we'll be able to transmit TV white space signals, but it will probably never be hundreds of kilometers, given the power restrictions on the signals as well as the limits of UHF and VHF antennas. So access to a fiber backbone will still be important.

Users of the Zomba network are now able to conduct research and communicate with colleagues in a far more timely way. The link to Pirimiti Community Hospital, for example, supports research and experiments in virtual diagnosis as well as the uploading of real-time X-ray images; remote medical specialists are able to watch and advise local staff during operations. Scientists in the government's seismology department, who previously had to wait up to a month for field data to be collected and sent to them on flash memory cards, can now access data in near real time. As a result, the country's disaster response has been enhanced.

TV white space technology has also been explored for use in more populated areas. Cape Town, South Africa, has the distinction of having the fewest vacant TV channels in the country, and hence it's the toughest South African site for deploying the technology. Yet in our trial, 10 schools—several of them in impoverished areas on the outskirts of the city—were connected with base stations at Tygerberg Hospital. The radio equipment was provided by Carlson Wireless, and the trial was operated by TENET (the Tertiary Education and Research Network of South Africa) with sponsorship from Google; the Meraka Institute of the Council for Scientific and Industrial Research (CSIR, where coauthor Johnson works) performed the field measurements to ensure that no radio interference occurred. In contrast to the trials in Malawi, the Cape Town network relied on both spectrum scans and predictions of signal propagation to match available TV channels with the GPS coordinates of devices in the network.

Prior to our project, those schools that had Internet access depended on out-



IN THE CLEAR: To avoid interfering with broadcast TV signals, a TV white space network can use a geolocation database, which lists channels currently in use, as well as spectrum scans, which detect available frequencies. TV white space signals have been sent up to 20 kilometers in the UHF band, providing broadband uplinks and downlinks to otherwise hard-to-reach rural sites. At the end points, the use of Wi-Fi provides access to smartphones, laptops, and tablets.

dated ADSL modems capable of only 1- to 2-Mb/s downlinks and 128- to 512-kilobit-per-second uplinks. Once the TV white space network was established, even the school farthest from its base station, 6.5 km away, achieved a throughput of 12 Mb/s on the downlink and 8 Mb/s on the uplink in a single 8-MHz TV channel. As in Mulanje, students and teachers throughout the network are now able to use services like Skype and stream educational videos.

The Cape Town trial was the first in the world to use white space frequencies adjacent to TV channels that were carrying broadcasts and also between two in-use channels. Previously, European and U.S. regulators had concluded that such frequencies should be avoided. But calculations at CSIR showed that using them would pose a problem only if the white space device was less than 200 meters from a television set. By positioning our equipment well away from sites likely to be receiving or sending TV signals, we avoided interference. The

results prompted the U.S. Federal Communications Commission to allow adjacent channels to be used in cases where power levels are sufficiently low.

Despite the success of these and other trials, telecom policy in many African countries has been slow to evolve. Indeed, spectrum regulation is still hemmed in by inflexible thinking from the early 20th century, when primitive wireless telegraphy was the going form of radio. Those century-old regulations require operators to secure a locked-down slice of spectrum in certain geographic locations; the operators might not always use their licensed frequencies everywhere they're allowed to. Many countries have yet to update their rules to allow the free frequencies to be repurposed. (For the trials described above, the researchers had to get special permits from their governments.)

In South Africa, the Cape Town trial led to a white paper with suggested technical rules and regulations for the use of TV white space technology. It then took

another two years for the country's telecom regulator, the Independent Communications Authority of South Africa, to issue a call for industry to comment on proposed regulations. The regulator is now using these responses as well as advice from academic and industry experts to formulate a position paper, which is expected by the end of this year.

Malawi has been moving slightly faster: Based on the trials in 2013 and 2015, MACRA published draft TV white space regulations and requested industry comments, and we're now waiting for the Ministry of Information and the Ministry of Justice and Constitutional Affairs to issue the final rules. With any luck, Malawi will have officially adopted TV white space usage before the end of 2016.

While we wait for regulatory reform, African researchers are continuing to develop TV white space technology to make it truly affordable and relevant. At CSIR, a team led by Fisseha Mekuria has developed a geolocation spectrum database that is the first to use the Protocol to Access White Space (PAWS), for automatically finding vacant TV channels. Using a standardized protocol like PAWS rather than a proprietary one ensures that users aren't locked into a particular vendor, which is important for keeping costs down and fostering common protocols, software, and components.

CSIR researchers have also adapted a high-performance wireless mesh node to use with TV white spaces, for sites that can't be reached with Wi-Fi. And they and others are working on cognitive radios—that is, radios that can automatically decide which frequencies and modulation techniques to use. One prototype is the White RHINO (for Whitespace Reconfigurable Hardware Interface for Computing and Radio), developed at the University of Cape Town. It was inspired by the RHINO radio, which was designed for the radio-astronomy project called the Square Kilometre Array.

In Malawi, coauthor Mikeka, through his consulting company, e-Communications Research Group (eCRG), has been developing antennas that can be used not just for TV white space signals but also for digital TV ser-

vices. eCRG is also carrying out comparative studies of commercial TV white space radios, to better understand their characteristics. In addition, the company is working on software to allow TV white space radios to adapt their transmission power and other features so as to protect primary users of the spectrum (TV broadcasters and viewers, mainly) from interference.

Through a partnership between the University of Malawi and the ICTP's Guglielmo Marconi ICT Wireless Laboratory, engineers have also developed a low-cost spectrum analyzer to allow practitioners in Africa to identify TV white spaces easily through spectrum sensing. Although spectrum-sensing devices haven't exactly lived up to their promise in preventing radio interference [see, for example, Mitchell Lazarus's



HELLO, INTERNET: Kondwani Nankhumwa, a Malawi cabinet member, says TV white space technology could lift Internet penetration from less than 10 percent to 70 percent by 2019.

IEEE Spectrum article on the topic last month], there's definitely a use for them in rural settings, where the spectrum is relatively uncrowded.

The spectrum analyzer used in Malawi won an award at the IEEE Global Humanitarian Technology Conference in October 2013 and has since been deployed in Zimbabwe and Kenya. Mikeka's group has been training African engineers and spectrum regulators from various countries who want to use it because they can't afford commercial spectrum analyzers. In the future, this innovation could lead to spectrum "safaris" to map the airwaves in different parts of the continent.

The challenge now is to keep the momentum going. Many regulators as well as many telecom-equipment man-

ufacturers have adopted a wait-and-see attitude. As a result, there is currently very little equipment available that is based on broadly accepted technical standards for TV white space such as IEEE 802.11af or 802.22. One exception is the Picasso Gen3 chipset from Carlson Wireless, released in April. It's the first TV white space chipset based on 802.11af, and in a press release the company claimed that the signal "penetrates walls, trees, foliage, and bends over hills even at long distances." More such developments would be welcomed by the many African scientists and engineers who remain committed to TV white space technology. Once the telecom authorities in South Africa and Malawi issue their decisions, we expect it to have a ripple effect on other African countries.

The South African government has a broadband plan for 90 percent of the population to have at least 5 Mb/s by 2020 and for broadband access to cost no more than 5 percent of a user's gross monthly income. Malawi, meanwhile, is procuring a 622-Mb/s Internet link from Lusaka, in Zambia, to Blantyre—Malawi's second largest city—and onward to Maputo, in Mozambique, which will connect Malawi with the UbuntuNet Alliance, the research and education network for eastern and southern Africa. Among other things, the connection will give the Malawi Research and Educational Network a 1-gigabyte-per-second fiber-optic link to the Internet at a price of less than \$80 per megabit per second, less than one-tenth of what it costs today. TV white space networks would then connect to that fiber backbone.

TV white spaces are just one example of a broad movement, known as dynamic spectrum access, which seeks to repurpose licensed wireless spectrum in geographical regions where it is underutilized. After TV white spaces are opened up for secondary use, the same model will likely be applied to other radio services and other frequency bands. Indeed, in the coming years, we expect to see this revolution overturn the way countries regulate and use their radio spectrum. **n**

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