ANU-MIMO: A Community Wireless Network Infrastructure for Remote Populations

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***Abstract*—Large-scale, scalable, distributed, decentralised MIMO (SDD-MIMO) [1] can be deployed to extend existing broadband infrastructure to remote communities. The network complements existing back-haul networks by providing an omni-directional broadband service to a large and scalable number of distant users distributed over a very large area. The Indonesian archipelago poses some challenging scenarios with its mountainous landscapes and some 18000 islands, often trans-oceanic and separated beyond horizon. In this paper, we propose SDD-MIMO as a solution for many of these difficult scenarios and present simulations for two representative examples.**

***Index Terms*—MIMO, wireless, scalable, distributed, decentralised, Internet, broadband, regional, remote.**

I. Introduction

Long range high capacity fixed broadband is a difficult problem to solve. The next generation 5G mobile technologies offers no solution. The solution of last resort, geosynchronous satellite, is impossible for individuals or communities to deploy and suffers from communication latency that renders many web services unusable and signal drop outs in regions affected by monsoon. Recently proposed solutions include Facebook's project Aries [2] based on centralised Massive MIMO and Google X's project Loon [3] to build a world-wide network of wireless-equipped balloons. However these are marginal enhancements to the current state of the art and like all centralised, cellular deployments suffer from key physical issues. Moreover like satellite, they cannot be implemented by the communities that need them.

The provision of fixed broadband to large geographically isolated populations needs a complete rethink. In [1] we argue that a truly community-base network that can scale incrementally to serve a large remote population must be scalable, distributed and decentralised (SDD-MIMO). At the Australian National University we are prototyping such a network known as ANU-MIMO. In this network, a large (essentially unlimited) number of service nodes (SNs) operating at VHF-UHF frequencies, each with a modest E.I.R.P. (equivalent isotropic radiated power) cooperate with each other to perform large scale beam-forming over distributed back-haul. This results in a multitude of high power, highly focused radio-wave beams that are capable of reaching distant users. Like existing large scale multiple Input Multiple Output (MIMO) systems, the aim of this technology is to deliver a fixed capacity to each user. More details on SDD-MIMO can be found in [1] where we treat issues such as user capacity, choice of carrier frequency and how the multiplicity of radio nodes leads to a significant reduction in RF power.

In this paper we investigate how such a network may be used to provide an economical fixed broadband solution for the particular case of Indonesia. Indonesia is a nation of over 17500 islands that are home to a population of 260 million. The islands are sometimes mountainous and usually separated by hundreds of kms of sea. Not surprisingly, Indonesia has a low fixed broadband ($> 256kbps$) penetration at 1.2% [4]. About 7717 villages have no connectivity at all. Many major towns situated in low-lying coastal areas have good Internet connectivity but reticulation by existing technologies is either blocked in-land by mountains or is beyond horizon over the sea. The state of affairs for mobile broadband is somewhat better at just over 30% penetration. But even this can be improved with better network infrastructure.

Indonesia has a broadband plan currently under implementation [5]. The government aims to raise fixed broadband penetration to 71% at 20Mbps in urban areas and 49% at 10Mbps in rural areas by 2019. To this end, a fibre ring is being rolled-out around the entire country [6]. However once a back-bone is operational, a solution will still be needed for the last mile connection. The SDD-MIMO network proposed here could go some way to help achieve this goal.

Better infrastructure for isolated areas is also a basic humanitarian requirement in times of natural disaster. World-wide, humanitarian communications support is an unsolved problem: involving a mix of military intervention, the amateur radio service and various other minimal infrastructure solutions. As the devastating consequences of the 2004 Tsunami have shown, nowhere in the world is the ready availability and efficiency of this support more important than in Indonesia. In this paper, we model a test case for fixed wireless broadband to demonstrate how mainland fibre at Padang in Sumatra, can be delivered over the sea to the island of Siberut, 155kms to the south-west of Padang with a population of 35000.

II. Network Architecture

The network consists of a very large number of Internet connected base stations or service nodes (SNs) and a large but smaller number of remote nodes RNs. The network can be built starting with a single SN and RN and can then be expanded by adding one or more SNs for each new RN added. This incremental roll-out feature is critical for economic viability. Two deployment scenarios are shown in Fig. 1. In Fig. 1a, SNs are installed on the roofs of buildings in a broadband connected town. The SNs use the existing back-haul network for both coordination for beam-forming and for connectivity to the Internet. Fig. 1b shows a solution for the case where there is no back-haul infrastructure. A broadband Ethernet switch connects a vast array of SNs through a star-network of microwave links. In both scenarios, the network has no fundamental size limit and can be scaled virtually indefinitely.

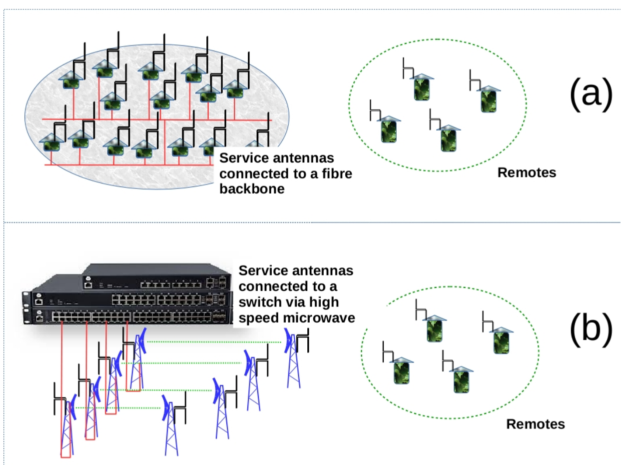

Fig. 1. Two example deployment scenarios of the proposed network.

III. Simulation Models and Parameters

Tables I and II show the model parameters employed in the simulations. The Hata model [7] is suitable for medium range urban-rural environments. We use it here to treat the common case of flat, cluttered terrain surrounding a town. This is a common scenario given that most of the worlds population lives within 100 kms of a town-centre. The ITU-R model [8] is applicable to the case of beyond horizon, trans-oceanic propagation including a lower limit estimate of signal strength due to troposcatter. This is a common scenario in Indonesia. For the simulations, we consider an SDD-MIMO network with conjugate match beam-forming. We use a detailed, fully deterministic communications model in which QPSK symbols are transferred over both the forward and reverse links taking into account the RF power, antenna properties, the link path-loss, conjugate match coding and the receiver noise. From this we guage performance by computing the up and down-link bit error rates (BER) by measuring the minimum RF powers required to achieve good results. In both models we assume that the target data rate is 10Mbps and channel bandwidth 10MHz.

TABLE I
Model Parameters for Test Case 1

Parameter	Value	Unit
Frequency	921	MHz
Bandwidth	10	MHz
Temperature	300	oK
Ambient Noise Figure	0	dB
Typical noise margin (typ.)	5-15	dB
Typical SN network geographical span	1	km
Antenna polarisation	vertical	
Typical RN range from SNs	50	km
RN distribution	scattered	
Range of SN numbers	1-4096	
Range of RN numbers	1-1024	
SN Antenna Height	10	m
RN Antenna Height	10	m
SN antenna gain	0	dBi
RN antenna gain	0	dBi
Channel	Hata	

TABLE II
Model Parameters for Test Case 2

Parameter	Value	Unit
Frequency	171.25	MHz
Bandwidth	10	MHz
Temperature	300	oK
Ambient Noise Figure	0	dB
Typical noise margin (typ.)	5	dB
Typical SN network geographical span	10	km
Antenna polarisation	vertical	
Typical RN range from SNs	155	km
RN distribution	ULA	
Range of SN numbers	1-4096	
Range of RN numbers	1-1024	
SN Antenna Height	10	m
RN Antenna Height	10	m
SN antenna gain	0	dBi
RN antenna gain	20	dBi
Channel	[8]	

IV. Test Case 1: Regional area surrounding a town

In this case we consider 1024 RNs scattered around a town centre with a random distribution of 4096 SNs operating on 921MHz. Indonesia has no sub-GHz class license band exceeding 10MHz bandwidth, so we use the 902-928MHz Industrial, Scientific and Medical (I.S.M.) band which may be licensable for test purposes. The range 915-928MHz is publicly available in the USA and Australia. In the second test we consider the possibility of redeploying the low VHF TV bands. For very long range infrastructure deployments it will be necessary to license the radio spectrum for this purpose. As pointed out in [1], the best opportunity may be the band I VHF channels on 54-68MHz. For dense deployments in or near to

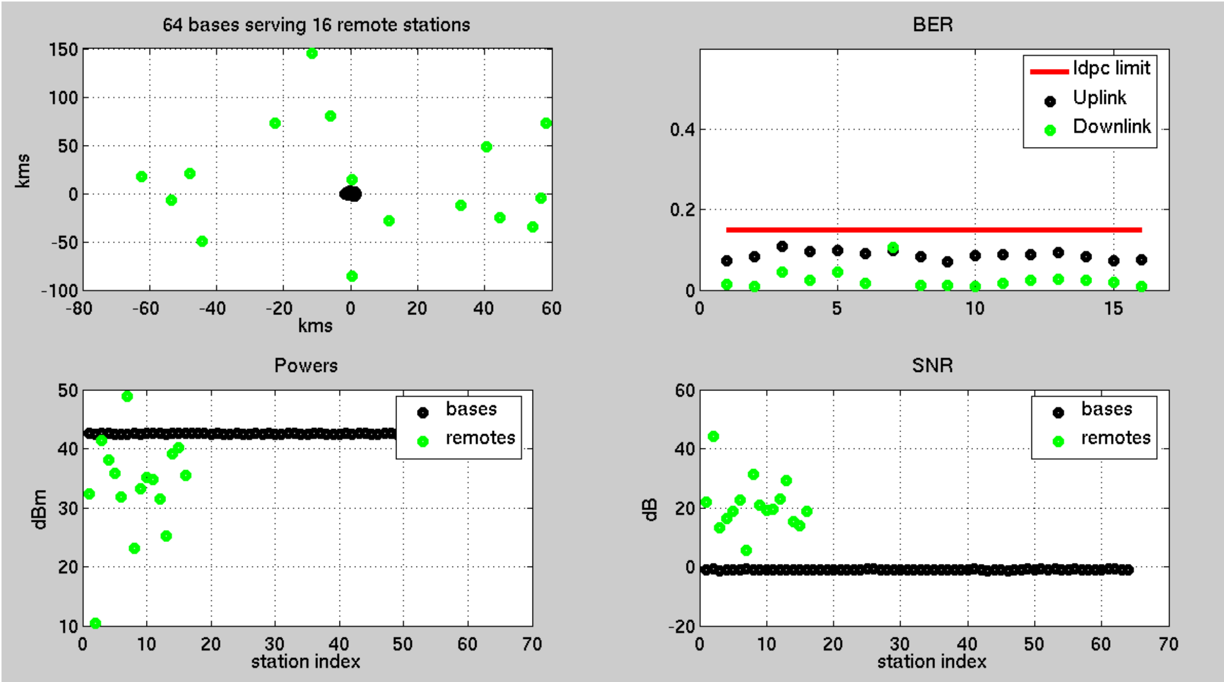

Fig. 2. Simulation results for an urban-rural link with 64 SNs and 16 RNs and the conditions of Table I.

towns or cities, the smaller wavelength of UHF frequencies such as 921MHz facilitates more compact installations.

We consider two cases to emphasise the need to incrementally roll-out the network. Firstly Fig. 2 shows the results for a SN/RN 64/16 network. Clockwise from top left are SN/RN spatial distributions, BER, SN/RN RF power (dBm) and SNR margin. High RF powers $\approx$ 50dBm (100W) are required for the longer range RNs. Even the SNs require about 43dBm (20Watts). This is too high for mass public spectrum deployment c.f. WiFi.

Fig. 3 shows the same deployment scenario but with 4096/1024 stations. The longest range RNs now require just a few Watts and the SN powers in the order of 20 dBm (100 mWatts).

We conclude that if we wish to deploy a network on 921MHz to serve a large population located at 100-200 kms around a town then we should connect the shortest range RNs first. Longer range RNs can be considered when the number of SNs is large enough to provide the aggregate power required to cover the range.

V. Test Case 2: Padang-Siberut

In this case, we consider the deployment of a 10Mbps per user SDD-MIMO link from the city of Padang located in western Sumatra to the island of Siberut. Siberut has a population of 35,000 and is located about 155 kms trans-horizon-over-sea from Padang. From the ITU-R model, such a link exhibits very high path-loss and ordinarily would not be considered a contender for a multi-Gigabit wireless link. Padang is a densely populated town of 1 million located at sea level. It appears to have good fibre back-haul so we choose a Fig. 1a roll-out strategy with the SNs in Padang and the RNs on Siberut.

With QPSK modulation and a $1/2-$rate forward error correcting code, SDD-MIMO can achieve 10Mbps per user on 10MHz of radio spectrum provided $SINR > 1$ across the network.

For Padang-Siberut we use the ITU-R P.1546-5 [8] trans-oceanic path-loss model with an antenna height of 10m at each end of the link. Such a low antenna height is to be expected if existing building infrastructure is to be used to support the network. The main pathloss effect here is not terrain but rather the curvature of the ocean requiring some assistance from troposcatter to make the link feasible. The SN antennas are low gain vertical dipoles under the assumption that they may be used to serve RNs from any direction around Padang. Since the RN antennas on Siberut must be oriented toward Padang, we deploy large 20dBi, vertically polarised Yagis so that we can save on RF power at each end of the link. Note that in most deployment scenarios the SNs will be confined to a general area that is much less than the expanse of the RNs. As a result, RNs can focus their RF powers in a fixed direction toward the SN network. We choose a carrier frequency of 171.25MHz which is assigned to channel 5 VHF TV but is not in widespread use in Indonesia. To serve 1024 RNs we deploy 4096 SNs and adjust the transmit powers of the RNs and SNs so that the raw BERs across the network are correctable (< 0.15). In this case, the link has an aggregate throughput of 10.24 Gbps or 1024bps/Hz. Note the huge spectral efficiency of the SDD-MIMO network. This is to be compared to the current state-of-the-art of about 80bps/Hz in a centralised massive MIMO [9].

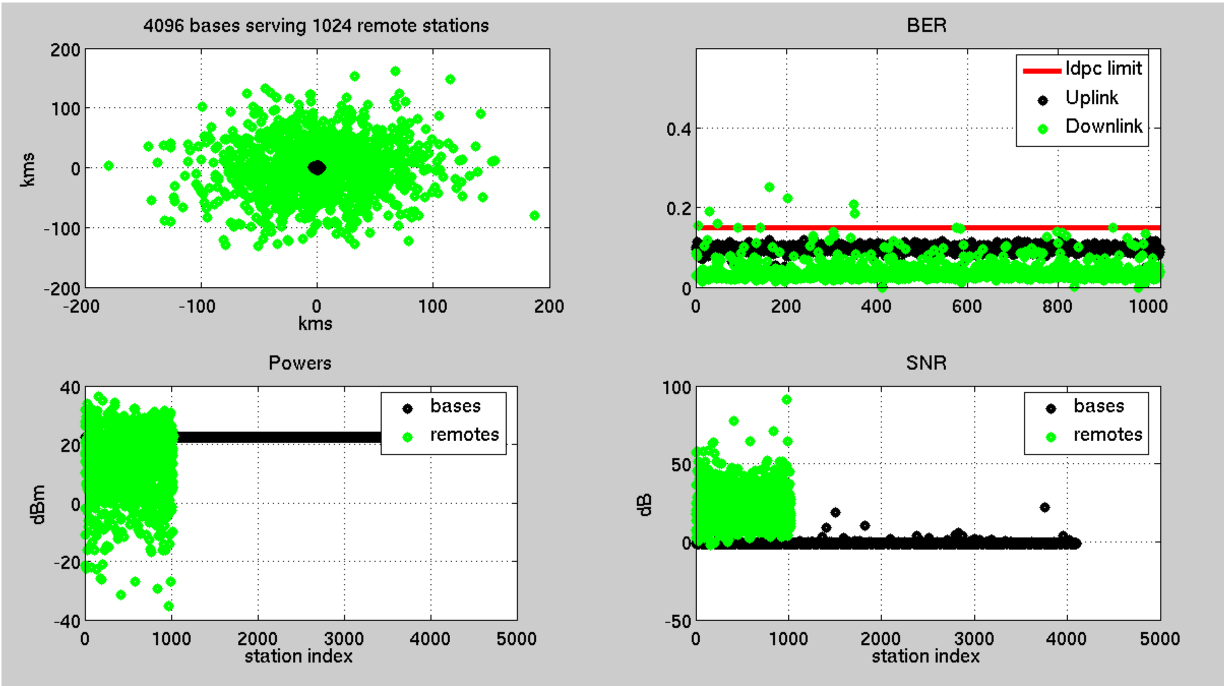

Fig. 3. Simulation results for an urban-rural link with 4096 SNs and 1024 RNs and the conditions of Table I.

Fig. 4 shows the results of the simulation. Top left shows a map with 4096 SNs in Padang (black) and 1024 RNs on Siberut (green). The top right figure shows the BER which has been held within range by careful choice of the signal margin.

The bottom left figure shows the RF powers of the SNs (black) and the RNs (green). The combination of beamforming and high antenna gain leads to very manageable RF power levels that are again typical of WiFi. The bottom right figure shows the SNR. For a detailed explanation of power and SNR scaling in SDD-MIMO please refer to [1].

We conclude that even a very difficult trans-oceanic link can be achieved using modest RF powers. SDD-MIMO may therefore be thought of as providing a very high capacity, long-range, consumer-grade WiFi technology.

VI. Conclusion

We have simulated SDD-MIMO networks for two common cases relevant to Indonesia. The simulations indicate that massive capacity networks can be run over vast distances even for over-the-horizon trans-oceanic links. For especially difficult links such as those in excess of 300kms over the sea, it might even be possible to install the SN network on a mountain top using the configuration of Fig. 1b if there is insufficient infrastructure available.

Acknowledgment

The authors would like to acknowledge the financial support of the Research School of Physics and Engineering at the Australian National University and the hospitality of the organisers of the ICCED conference.

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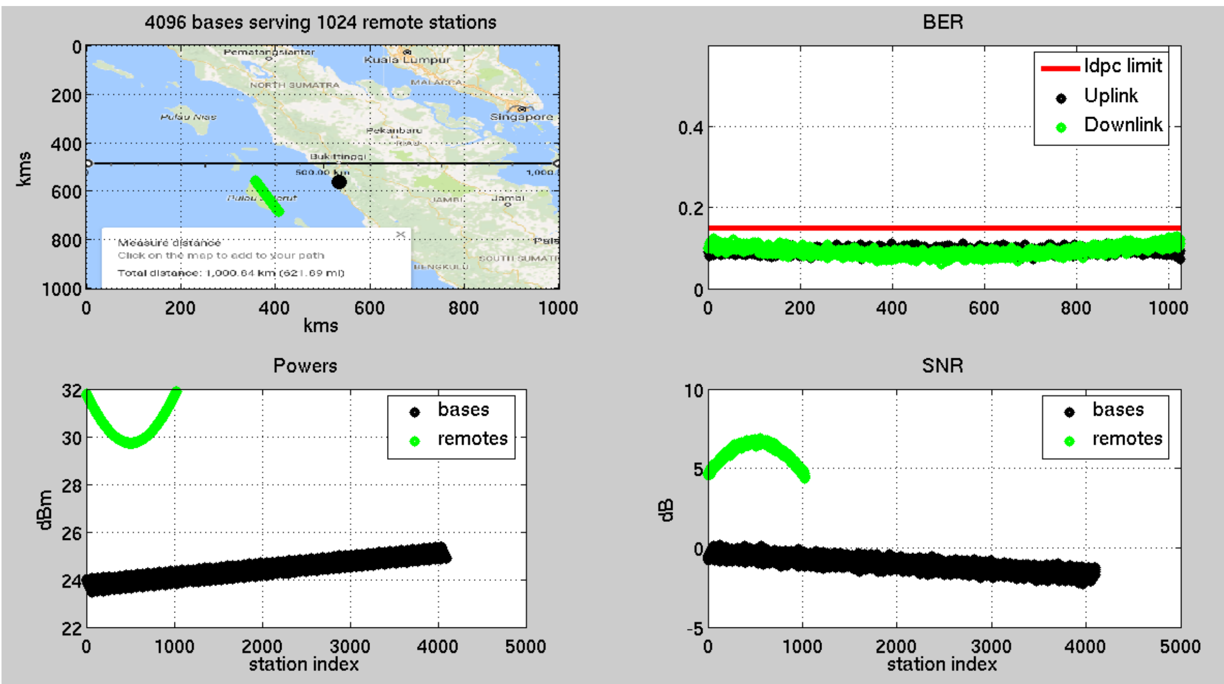

Fig. 4. Simulation results for the Padang-Siberut link for the conditions of Table II. .