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저소득 원거리 소외지역에서 무선통신망 지원을 위한 다중계층 모델 접근법

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A Multi-Disciplinary Layered Model for Wireless Connectivity in Low-Income Remote Rural Areas

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요 약

현재 무선통신 시스템과 사업모델은 저개발 국가의 저소득 원거리 소외지역의 현실에는 적합하지 않다. 이 논문에서는 이러한 저소득 원거리 소외지역의 사회문화, 경제, 환경적인 조건들을 분석하여 현재의 접근법들이 적합하지 않음을 구체적으로 보이고, 저개발 지역에 적합한 네 개의 계층과 여러 분야로 이루어진 연결 모델과 각 계층별로 맞는 무선통신 구조들을 제안한다. 또한 제안하는 계층 모델에서 전통적인 국제 원조기구들의 역할과 지역사회의 역할을 분석하고 제시하는 무선 기술의 특징들을 밝힌다. 마지막으로 최근 관심이 집중되고 있는 차세대 무선 기술들이 제안하는 모델에서 어떻게 사용될 수 있을지를 살펴본다.

Key Words : Wireless communications, wireless for development (W4D), multi-disciplinary, layered model

ABSTRACT

Current wireless communications systems and related business models do not suit realities in low-income remote rural areas (LIRRA) in developing countries. In this article, we first analyze socio-cultural, economic, and environmental conditions in these areas to illustrate the inappropriateness of current approaches. Then, we propose a more adequate four-layered multi-disciplinary connectivity model and a matching wireless system architecture to specifically and durably connect these under-privileged areas. The proposed model and technological choices exploit strengths and weaknesses of LIRRA to derive befitting tradeoffs. A particularity of the proposed model is that it accommodates key traditional international development partners. Existing and future wireless technologies are also analyzed vis-à-vis the proposed model.

Ⅰ. Introduction

Bridging the digital divide has been a key millennium development goal. However, this goal is not being achieved, as billions are still disconnected from the rest of the world. These populations live in low-income remote rural areas (LIRRA) in developing countries and are ignored by

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telecommunication operators. Few proposals have been made in the literature to connect LIRRA. For instance, wireless fidelity (WiFi) access to a satellite backhaul was suggested in [1], while code division multiple access in the 450 MHz band (CDMA450) was advocated in [2] for the access network. Unfortunately, these laudable contributions and many others did not translate in reality. One reason is that most of these proposals do not address energy and affordability issues, which are identified further in this article as the main challenges to telecommunications in LIRRA. Another reason is that workable business models that account for realities on the ground have not been matching technical proposals. Even funded initiatives by Facebook [3] and Google [4] are partial solutions only, and might fail to fully meet their objectives if other dimensions of the LIRRA connectivity issue are not addressed.

In fact, solving LIRRA's connectivity problems necessitates a cross-disciplinary approach. In this article, we propose a wireless network architecture that is based on a socio-economical, environmental, and technical analysis of strengths and weaknesses of LIRRA. The inadequacy of current business models and technical options is demonstrated. Noting that local communities (LC), governments, international aid agencies (IAA) and non-governmental organizations (NGO) always play key roles in all developmental projects in LIRRA [5], a four-layered multidisciplinary wireless-for-development (W4D) model is proposed to include these indispensable partners. The proposed model comprises content, backhaul, access, and end-terminal (CBAT) layers. For instance, rural connectivity efforts by Facebook (Amos-6 satellite) [3] and Google (Loon project) [4] are typical backhaul layer initiatives. At each layer, key technical, social, and financial players are identified, along with reality-aware technical design requirements. After a thorough analysis of available technologies at each layer, a W4D technological solution is proposed. Furthermore, the potential inclusion of cutting-edge wireless technologies to the proposed W4D model is explored. Our choice of an all-wireless connectivity solution does not undermine the generality of the CBAT model. At our knowledge, contributions with such crossdisciplinary approach, coupled with multi-stage technological design for LIRRA connectivity are not common in the literature.

In the remainder of the article, section II exposes flaws in current telecommunication approaches with regard to LIRRA. The CBAT model for development and the matching wireless system design are presented in sections III and IV, respectively, followed by concluding remarks in section V.

Ⅱ. Inadequacy of Current Technological and Business Models

2.1 Realities in LIRRA

Before an efficient connectivity solution can be designed for LIRRA, a meticulous assessment of their situation is necessary.

1) Geography and environment: LIRRA are isolated areas, with relatively small population clusters. Sometimes located in mountainous areas, it difficult to access the area due to nonexistent or bad road networks. Their prevalence is highest in least developed and poor countries. According to world development indicators published yearly by the World Bank on its website, these countries are mostly located in Sub-Saharan Africa, with a few exceptions in Asia. Isolated communities in Amazonian and Indonesian jungles share similar characteristics. They are mostly sunny tropical regions.

2) Cultures and livelihood: LIRRA dwellers live of rudimentary and seasonal agriculture. They sell their production (e.g. cotton, coffee, cacao, fruits) once or twice a year and each individual earns less than 1$ per day on average [6].

3) The energy nightmare: LIRRA are rarely connected to national power grids and the lack of electricity constitutes a hindrance not only to information and communications technologies (ICT), but also to all activities that could improve the livelihood of those communities and enable their

development.

4) Potential assets for wireless communications: Because of their isolation, connecting LIRRA among themselves, on one hand, and to the rest of the world, on the other hand, can be efficiently achieved through wireless communications only. The needed energy for wireless communications can be produced by wind turbines and solar panels [7], as most LIRRA enjoy 365-day sunshine. Moreover, their remoteness enables large amount of radio spectrum to be used because the risk of interference to other systems is minimal. In sum, abundant renewable energy sources and large spectrum resources constitute key wireless communications assets in LIRRA.

5) Development partners: Financial and human resources to assist peasant populations in LIRRA has always been provided by IAAs, NGO, and governments in sectors such as health care, education, potable water, agricultural advices, micro-finance, and sometime electricity [5]. These organizations were described in [5] and references therein as implementers, catalysts, and partners of developmental projects. They may equally support W4D projects. Additionally, big ICT firms such as Facebook and Google are already very active on rural connectivity and are classified as IAAs in the context of this article. Governments and regulators may also play a significant role.

2.2 Overview of current ICT issues in LIRRA

ICT are quasi-inexistent in LIRRA because of repulsive business conditions such as the heavy backhaul infrastructural investment needed, coupled with villagers' lack of financial means to consume services and contents provided.

1) The lack of development-oriented contents: Contents proposed by ICT operators are widely irrelevant to development needs of LIRRA populations. National radio and television programs, which are the only rarely available means of information, are a drop of water in the vast sea of multimedia contents accessible by Internet. If available, these programs serve entertainment purposes, rather than developmental goals. Challenge to developing suitable contents for LIRRA are exposed in [6].

2) Current ICT: Technologies deployed to facilitate the development of LIRRA are inexistent in most countries of interest. Costly satellite and microwave links [8] are generally the only available options for backhauling. In rare cases of available connectivity, it is based on standard second generation (2G) macro-cell mobile access because mobile network operators (MNO) try to cover as much area as possible with a single base station or access point (AP). However, 2G technologies suffer not only from low data rates that exclude development-oriented multimedia contents, but also from energy-unfriendliness to end-user-terminals (EUT). This is because long transmitter-receiver distances yield high energy consumption.

3) End-user terminals: With the increased demand for multimedia contents, mobile phone manufacturers focus on profit making terminals with large display and touch screen. Even for a voice conversation, dialing a number or receiving a call illuminates the terminal's screen. Unfortunately, this increasing trend is detrimental to W4D efforts in LIRRA because displaying amounts for a large portion of battery power consumption in these expensive EUT.

4) Business models and role of LCs/NGOs/IAAs, governments, and regulators: In the business models widely used currently, MNOs provide EUT, access network, backhaul, and even contents to end-users in one single contract. They also do not differentiate poor rural regions from rich urban areas in their pricing policies. These business models cannot fit in traditional developmental paradigms that are built around financial and technical support from LCs, NGOs, IAAs, and governments. In these proven developmental models [5], LCs, which are obviously stronger than individual villagers, act on the behalf of the peasants in most compartments of their lives. This is incompatible with current business models. Moreover, current approaches do not provide flexibility to individual NGOs to assist LIRRA at particular levels (i.e., terminal, access network, backhaul, or contents) of the connectivity problem.

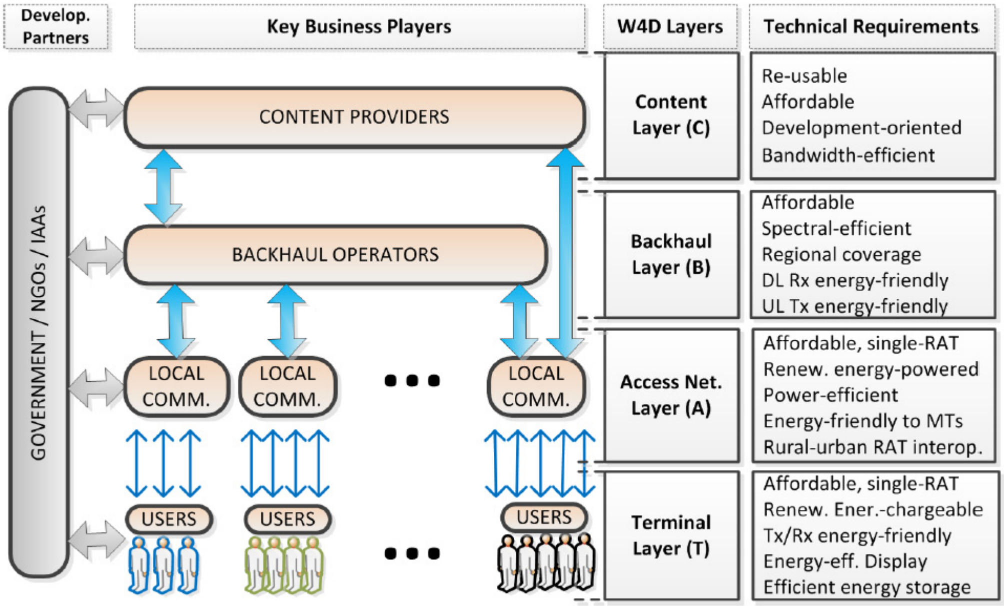

그림 1. W4D를 위한 CBAT 계층 모델
Fig. 1. The CBAT layered model for W4D

5) The investment-attractiveness of urban areas: It is not surprising that MNOs concentrate their investments on improving their urban networks and turn their backs on LIRRA. Not only is it more costly to build a backhaul connection to a remote rural site than to an urban site, but a quote in [4] also suggests that revenue generated by a rural site is 946 times smaller. Because of this, the pure profit-only-based model is unlikely to work and an alternative development-based model for LIRRA connectivity is imperative.

Ⅲ. The Proposed CBAT Model

Clearly, it is unlikely that an NGO provides funding to individual fishermen/farmers in a LIRRA for connectivity contracts with an MNO. However, an NGO, an IAA, or a government/regulator may be willing to: (1) distribute solar-powered EUT and/or modem-equipped large-screen televisions to LCs; (2) finance the construction of a solar-powered local access network for a LC; (3) pay for a backhaul link operation contract for LCs; (4) pay for the development and the production of development-oriented contents; or (5) provide free spectrum for community-based W4D operations. By the layering of LIRRA connectivity, opportunity is provided to development partners to participate toward W4D at layers that match and suit their individual mandates. The four-layered proposed CBAT model is illustrated in Fig. 1 and described below.

3.1 Content layer

The content layer (CL) produces development-oriented contents and applications beyond traditional voice. These may include tele-medicine applications, tutorials on agricultural techniques, water sanitation, environmental protection, prevention of HIV and other diseases, snake bite handling, family planning, civic responsibilities and elections, human rights, basic economy and management, female education, language trainings, news, and many other subject inherent to sustainable development.

1) W4D requirements: To attract villagers' interest, contents must ideally be audio-visual. For affordability, they must run on open-source platforms and be re-usable. A video content produced in Swahili for Tanzanian villagers should

be enjoyable to Ewe villagers in the Republic of Togo or Ghana, just by changing the language before transmission. Data compression schemes remove redundancy in multimedia contents, hence reducing their size before transmission (storage) over band-limited channels (memory-limited disks). However, highly compressed data will require more processing power at the receiver for decompression. For power-limited W4D terminals, compressed data becomes a challenge. Therefore, the format of W4D contents should strike the right trade-off in favor of receiving power-efficiency. Additionally, delay-tolerant applications could be less challenging to the network.

2) Key players : Content providers are generally profit-making organizations. However, development partners and governments may pay for these contents and use them all over the world. Smaller NGOs and universities may also support. Even LCs may directly purchase contents they deem relevant.

3.2 Backhaul layer

The backhaul layer (BL) connects LIRRA among themselves and to Internet. Wireless transmission techniques are the default backhaul choice.

1) W4D requirements: Chosen technologies should be energy-friendly to remote access points, both in uplink and downlink. Simple cost-effective technologies with wind/solar-powered transceivers should be used. Furthermore, multi-hop transmission techniques may provide power-efficiency and architecture flexibility. For rural regional coverage, spectral efficiency might not be a key requirement.

2) Key players : Governmental telecommunications agencies, private backhaul operators (PBO) and/or NGOs/IAAs may provide technical expertise and/or funding at this layer. The backhaul layer of the W4D model can be publicly owned or privately owned by PBOs, with government support (free spectrum, tax incentives, etc.) to reduce cost for LCs. Private corporations such as Facebook [3] and Google [4] are likely to play increasingly important roles at the BL.

3.3 Access network layer

The access network layer (ANL) connects EUT to W4D’s BL.

1) W4D requirements: The access layer should have the same energy and cost requirement as the backhaul. Wind/solar-powered APs should cover small cells to minimize power usage at EUT. Access technologies should prioritize energy-efficiency over spectral-efficiency because abundant spectrum is a key asset at LIRRA. Open access technologies may be used in an attempt to reduce cost. Intra-village handover, inter-village roaming, as well as interoperability with urban mobile systems should also be supported. Finally, only a single access technology without multiple radio access technologies (RAT) should be used at the ANL to reduce terminal complexity and cost.

2) Key players : Access networks should be owned by LCs. They may outsource technical management to private contractors or hire full-time technicians. Development partners and governments may support financially or fiscally in purchasing, deploying, and/or operating APs, as well as in paying PBO’s services. Because villagers generally sell their agricultural products annually or semi-annually through LCs, small contributions may be deduced from their revenues to assist toward funding their connectivity needs.

3.4 Terminal layer

The terminal layer (TL) is the bottom layer of the model.

1) W4D requirements: Affordability and power-efficiency are the main requirement on a W4D EUT. It requires attached solar-powered battery-charger module, big battery storage ability, larger antenna size for higher gain. If battery-charger modules are not provided, users may have to charge their batteries at a public solar-powered station. To further save energy usage, even though an EUT should have reasonable size screens, full screen display may occur only for image/video applications. It should have traditional keypad for input instead of a touch screen. To reduce hardware complexity and cost, only a single RAT should be supported.

2) Key players : EUT are used by villagers and may be their proprieties. They may also be owned by LCs that may rent to villages in exchange of marginal contributions, which could also be deduced from their annual incomes. Modem-equipped public big screens are other types of EUT. NGOs and/or governments may subsidize terminals, by funding their design and/or canceling import duty on them.

3.5 From the CL to the TL

The CBAT model allows operational flexibility, as the CL can be directly connected to any other layer in the model, operationally, technically, or financially. For instance, LCs can purchase contents on a storage device directly from content providers, broadcast them through loud speakers in the village or display them on large screens in public places. In this CL-TL direct connection, the BL and the ANL are bypassed. Stored contents can also be sent to EUT through ANL APs, hence bypassing the BL.

3.6 The renewable energy solution

It is shown in [7] that village-level solar energy is a very efficient and practical way to power off-grid communities. Leveraging approaches presented in [7], every layer of the CBAT model can be powered. For instance, EUTs or charging modules may be grouped with lanterns, while power-efficient APs are grouped with offices. Techniques suggested to resolve challenges are equally applicable to W4D powering.

3.7 W4D catalysts

Just like in any developmental project in LIRRA, LCs, NGOs, IAAs, and governments must play key roles in connecting these communities and providing them with useful contents. They act like expertise and funding providers, catalyzing activities at every layer of the W4D model, as shown in Figure 1.

Ⅳ. A Wireless System Architecture for the CBAT Model

4.1 Overview of potential wireless technologies for the CBAT model

Available wireless technologies and their suitability for W4D's backhaul and access layers are analyzed in this section. A summary is shown in Table I.

1) WiFi, and WiLDNet: IEEE 802.11 Wireless Fidelity (WiFi) standards support high theoretical data rates (up to 600 Mbps for IEEE 802.11n), and cover hundreds of meters outdoor. Deployment is done in unlicensed bands at relatively low cost. However, power consumption is relatively high for interference-prone WiFi access. In the context of W4D, solar-powered outdoor WiFi could be a potential access network layer candidate. Unlike traditional WiFi, WiFi-based long distance networks (WiLDNets) may theoretically cover up to 100 km with significant changes to WiFi's medium access control (MAC) protocols [12]. WiLDNets may serve on the backhaul layer, connecting regional towers to village WAN APs with their directional links, as shown in Figure 2. They are not suitable for W4D's access network layer because of the high transmission power required for long distance communications.

2) WiMax and IEEE 802.20: Worldwide interoperability for microwave access (WiMAX) is defined in multiple versions of IEEE 802.16 standards. It has higher throughput and covers wider distances than WiFi and is mainly used as backhaul link for hotspots [11]. However, its IEEE 802.16m version and its sister IEEE 802.22 standards are strong mobile access candidate as well [13], with an optimum performance when covering between 0 and 5 km. Although high equipment and device cost disqualifies WiMAX for W4D access network layer, it might be used for backhauling.

3) Wireless WAN technologies: Mobile wide area networks (WAN) are the most widely used technologies for wireless network access. While 2G technologies such as the Global System for Mobile Communications (GSM) were optimized for low-rate voice communication, 3G and 4G systems theoretically support high data throughputs up to 1 Gbps, i.e., Long-Term Evolution-Advanced (LTE-A). Higher data rates and intra-village, inter-village and rural-urban mobility/roaming support are their strength for W4D access.

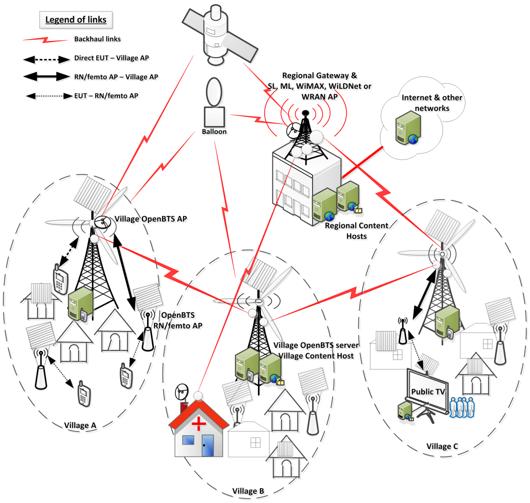

그림 2. 제안하는 W4D 구조도
Fig. 2. The proposed W4D architecture

Nevertheless, they have to be deployed in micro-cell and femtocell architectures to reduce device power usage. Macrocell deployments cannot be envisioned for W4D inasmuch as power is scarce at user-terminals. Moreover, due to the complexity of state-of-the-art techniques used in 3G/4G systems, power usage is generally high. Their other main weakness is their extremely high cost at all levels, i.e., user-terminals, radio access network (RAN), and core network.

4) OpenBTS platforms: OpenBTS and related projects publicly provide software implementations of 2G/3G/4G WAN systems. All core network and radio resource management functionalities can be performed on a single OpenBTS server. Interconnection and interoperability with existing urban mobile systems is also supported. Moreover, the OpenBTS air interface can use software-defined radio transceivers with no technology-specific hardware. Big advances toward the implementation of a full LTE system on OpenBTS through the OpenIMSCore were reported in [14]. In addition to the advantages of 2G/3G/4G systems, customized implementations of low-cost low-power OpenBTS systems offer a unique opportunity to avoid complex proprietary techniques and achieve system simplicity. Two deployment paradigms may be envisioned: (1) local communities manage their own individual networks fully (core, RAN, and subscribers) with intra-village communications, while the backhaul layer provides inter-village, rural-urban, and Internet connectivity; (2) multiple local communities share the same OpenBTS core network server which is connected to Internet and urban systems, while they manage their individual RANs only. This latter approach poses subscriber management and backhaul signaling overload challenges and may need further investigation.

5) Microwave links: Line-of-sight (LOS) microwave links are essentially used for backhauling. The LOS requirement increases their deployment cost as large number of relaying towers are required between two distant locations. However, they guarantee a more stable quality-of-service (QoS) when compared to other non-LOS solutions [11]. Despite high initial deployment cost, microwave links are candidates for rural backhauls.

6) Balloon-enabled links: Balloons can replace high towers to improve LOS and coverage. Balloon-enabled microave links suffer less path-loss and delay than satellite links, but provide narrower coverage as well. Google's "balloon-powered Internet for everyone" project uses balloon-enabled microwave links.

7) WRAN and TV white space: IEEE 802.22 wireless regional area network (WRAN) standards use freed analog radio/TV channels in the 54-862 MHz bands (TV white spaces) to provide broadband connectivity to areas up to 30 km away from the AP [15]. With channel bonding, the data rates may reachmultiples of 22 Mbps at cell edges. The availability of TV white spaces in LIRRA makes IEEE 802.22 attractive for W4D's backhaul layer. However, complex techniques such as cognitive radio may increase system cost.

8) Satellite links: Satellites have wide coverage and satellite links are ideal for remote areas, despite the long round trip delay they experience. However, they require large antennas and high transmit power and do not suit for network access in LIRRA. Even though they might be used for backhauling, their exorbitant cost [11] is a challenge for W4D.

4.2 Proposed W4D network technologies for LIRRA

1) Access network layer: Depending on village sizes, a few APs may connect terminals (downstream) to the regional backhaul (upstream). Generally, one 3G/4G OpenBTS microcell should cover a community and provide core network functionalities including authentication and authorization, interconnection, subscriber management, mobility, roaming. The choice of OpenBTS is motivated by its equipment cost efficiency and inter-operability with urban 3G/4G systems. Urban visitors (e.g., tourists) could technically roam to the village network and villagers

표 1. 다양한 무선기술들에 대한 요약
Table 1. Summary of wireless technology options

W4D Layer	Technology	W4D Advantage(s)	W4D Disadvantage(s)	Recom. for W4D	Remark(s)
Access layer	WiFi	low cost, high flexibility	poor QoS support, no mobility/roaming	NO	not inter-operable with urban 3G/4G
	WiMAX	better coverage and QoS than WiFi	high equipment cost, high power consumption	NO	Equipment too costly, not inter-operable with urban 3G/4G
	OpenBTS (basic 3G/4G)	low cost, mobility/roaming, microcells/femtocells/relays, customizable complexity	potential open-source-related funding and coordination issues	YES	inter-operable with urban 3G/4G, flexible complexity, adequate for single-RAT
	State-or-the-art 3G/4G	inter-operable with urban 3G/4G	high cost, high complexity	NO	too costly with proprietary technologies
Backhaul layer	WiLDNet-WiMAX	no LOS req., limited single-hope coverage	complexity, multi-hop for large coverage	reality-dependent combinations	strong in hilly areas
	WRAN	available TV white space spectrum	complex technologies, high cost		weaker than WiLDNets-WiMAX due to complexity and cost
	Microwave links	flexible topology for content sharing, may use existing infrastructure	high cost, LOS requirement		strong on plain terrains
	Balloon-enabled microwave links	wider coverage than microwave, less loss and delay than satellite links	rigid topology, narrower coverage than satellite links		strong in both mountainous and plain areas
	Satellite links	flexible coverage	high cost, rigid topology		may be sponsored by big donors for large regions [3]

could visit urban networks. Moreover, big NGOs, international aid agencies, and/or governments could fund the customization and large-scale cost-efficient production of OpenBTS for numerous LIRRA. To save energy, femtocells or relay nodes may add another layer to bring APs closer to user-terminals.

2) Backhaul layer: Satellite links, balloon-enabled microwave links, WiLDNets-WiMAX, microwave links and WRANs provide sufficient data rates for the backhaul layer. While the cost drawback of satellite links may be bore by initiative such as Facebook's satellite project for rural Africa [3], the complexity of WRANs makes them weaker candidates. Despite relatively high deployment cost of microwave links, they represent a mature and stable option that can leverage existing broadcast relaying infrastructure in most developing countries. Satellite links and balloon-enabled microwave links support star topology only but the others candidates can support other topologies such as mesh and hybrid topologies. Therefore, they may provide better inter-village connectivity and redundancy than satellite links, as topological flexibility is critical for content sharing among local communities. Microwave links require LOS while WiLDNets-WiMAX, and WRAN do not. Additionally, WiLDNets-WiMAX, and WRANs can leverage on abundant spectrum in LIRRA to offer better data rates and QoS, even though they require multiple hops to cover long distances. Balloon-enabled microwave links offer lower delay and path-loss and may cost less than satellite links, but they cover less area. Table I summarizes characteristics of backhaul layer technologies for W4D. Ultimate choices should depends on country and LIRRA-specific realities. Combinations of backhaul layer technologies may be more effective than any single choice.

3) Multiple access and duplexing: OpenBTS-enabled 3G and 4G are suggested for access network layer. However, wideband code division multiple access (WCDMA) (3G) and orthogonal frequency division multiple access (OFDMA) (4G) have different characteristics. While OFDMA provides better QoS, spectral efficiency, and sector capacity than WCDMA, the latter is more attractive in terms of power efficiency, transceiver complexity and cost, as well as availability in case of urban roaming. This means that 4G will deliver better development-oriented multimedia contents and bandwidth-sensitive applications (e.g., tele-medicine) while 3G will consume less energy and will be more affordable to LIRRA users. For uplink/downlink duplexing, time division duplexing (TDD) has an edge over frequency division duplexing (FDD) for W4D, thanks to the lower terminal cost and energy consumption of the former.

4) Additional energy saving techniques: Beyond the proposed architecture, W4D operation may adopt other energy saving techniques [16], including shutting off transmitter power amplifier or receiving circuit during idle periods, and reducing the operating bandwidth. Furthermore, some signal processing operations such as channel encoding and encryption at user-terminals may be need-based. This means that for very good channels, sophisticated error control mechanisms can be avoided. Standard cryptographic requirements may also be lifted when security is not critical. Content data caching at local communities level may be another efficient technique to reduce backhaul traffic, energy consumption, and cost.

5) Multi-hop connectivity: Intermediary solar-powered nodes such as access relay nodes and femtocell APs at the access network layer and transmission relays at the backhaul layer, improve power and spectral efficiency of the system. Unfortunately, these multi-node connectivity approaches have drawbacks that include processing delay at each node, additional equipment cost, additional equipment and network complexity. Furthermore, small cells may lead to excessive handover overheads at the access network layer. Notwithstanding, we believe these approaches are particularly appropriate for remote energy-constrained users.

4.3 5G-enabling technologies and W4D networks

Technologies likely to enable 5G were analyzed

표 2. 5G 요소 기술과 W4D
Table 2. 5G-enabling technologies and W4D

Emerging wireless & networking technologies	**Main objective(s)**	**Weakness via-à-vis W4D**	**W4D Suitability / Layer (s)**
Dense heterogeneous networks	flexible coverage, spectral & power efficiency	may need multi-RAT terminals, too complex and costly for W4D	Possible / backhaul layer, access network layer
Millimeter waves	use of unused 10-300GHz spectrum	huge pathloss, spectrum is not an issue in LIRRA	No
Massive MIMO	spectral and power efficiency	complex signal processing, costly, spectrum is not an issue in LIRRA	Possible / backhaul layer, access network layer
Coordinated multipoint	interference reduction, improved spectral efficiency	complex, delay	No
Energy harvesting	cheap constant power anywhere, suitable for LIRAA	high initial investment, storage issue	Yes / backhaul layer, access network layer, terminal layer
Mobile clouds	cooperative & efficient computing, fast content sharing	constant need of connection, slow	Possible / terminal layer
Cloud-RAN	RAN resource efficiency	too complex, RAN delay	No
Network virtualization	hardware cost reduction	complex and slow, amplifies single physical failure	Yes / All layers

in [6] and references therein. The suitability of these cutting-edge techniques to W4D is summarized in Table II. It is argued that just like their urban 3G/4G predecessors, key 5G-enabling technologies will be generally out-of-reach, impractical, and irrelevant to LIRRA users and their terminals because of their inherent high complexity and cost. However, the backhaul layer might benefit from 5G techniques that would improve capacity and energy efficiency, if they are affordable. Moreover, content sharing and cooperative computation techniques, as well as hardware cost-saving network virtualization techniques may be useful to W4D. In sum, the impact of 5G-enabling technologies on LIRRA connectivity will be extremely marginal because they are being designed for resource efficiency in dense urban areas. This is corroborated by the assessment in [4].

V. Conclusion

In this paper, we propose a four-layered connectivity model that departs from traditional models by breaking the LIRRA connectivity problem into four distinct sub-problems, one at each layer. This simplifies the solution process by finding a technical, a financial, an operational, and a business sub-solutions at each layer. The model also provides a global multi-disciplinary framework for rural connectivity. While OpenBTS is suggested for the access network layer, specific backhaul layer designs may require diverse combinations of technologies. Improvements to these technologies by means of state-of-the-art 4G/5G techniques are further invoked. A very important feature of our proposal is the integration of development funding partners who seem indispensable for any project related to LIRRA. While the proposed model can be the basis for cross-disciplinary research on ICT for development, real case studies are needed. Specific content layer, access network layer, and terminal layer projects to complement Facebook and Google's backhaul layer initiatives, would be very useful. Furthermore, the proposed layered approach may serve as basic framework for national policies across the developing world.

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