The Shortcomings of Globalised Internet Technology in Southern Africa

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Abstract. Network protocols and applications have mostly been developed in and for a Western context and usually have an embedded set of assumptions about network performance and availability. As a result web-browsing, cloud-based services, live voice and video over IP, desktop applications and software updates often fail or perform poorly in (rural) areas of Southern Africa. This paper uncovers some of the reasons for this poor performance such as Windows TCP failing to reach capacity in high-delay networks, long DNS delays or time-outs and applications such as Office365 assuming constant connectivity to function, and describes them, set in the Southern African contexts. We address the issue of colonisation in ICT context and show the extend of such in the area of networking. These observations provide strong motivation for Africa-based engineering research to ensure that future network protocols and applications are context-sensitive, adaptive and truly global.

Keywords: Internet · Technology · Context · Africa · TCP/IP

1 A Critique of Internet Technology from an African Position

The global society relies heavily on the use of technologies to breach the imperatives of physical distances [1]. Especially Information and Communication Technologies (ICTs) are instrumental in connecting people irrespective of location, in the so-called Information Society. The assessment of the interrelationships between technologies and society depend on the academic approach and philosophical perspectives one subscribes to. In his meta-analysis of various approaches, Wolfgang Hofkichner [2] observes an academy engaged in a battle of theories, mostly bifurcated in what he calls *projectivisitic* social theories informed by social constructivism and *reductionistic* natural theories linked to technological determinism. In the mean time, society moves on. In their effort to link more users to their service platforms, corporate businesses drive target

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settings in provisioning of access to the internet. These targets mostly address issues of connectivity, bandwidth and affordability [3,4]. Subsequently, several countries have set goals for internet access in their national laws, e.g. South Africa Connect [5].

Internet, in many narratives, is regarded crucial as an enabler of human rights like the freedom of expression and opinion, among others. The inventor of the internet, Vint Cerf [6] agrees with this notion. However, he argues, internet should be considered as a tool and not be positioned as a right itself. Tim Unwin [7] indicates that the ongoing and growing disparities in access and usability of ICTs are an important source of accelerating inequalities. He quantifies a growing gap in subscribers to mobile networks, between the so-called developed and least developed countries, till 2012. Also, he observes that technological advances in the richer countries of the world generally outstrip those in the less affluent countries. From his analysis, he derives that "the rich have been able to gain the benefits, leaving the poorest and most marginalised ever further behind" [7, p. 5].

In our African context, the utilisation of ICTs is affected by persistent poor user experiences that result from a myriad of environmental, skills and cultural factors [8–11]. There appears to be a lack of African expressions of technology [12] and a contextualised wording and local framing of the use of ICT [4]. Currently, African contributions are sub-alternalised in a dominant *lingua franca* or a single story of a globalised technology use. For technology to be truly globalised, we argue, ICTs deployed outside of their context-of-design must be subjected to a post-colonial critique. In this paper, we apply such a critique. From a reflexive stance and technical laboratory research, we discuss some of the shortcomings of internet technology in the African setting. We propose that the current and ongoing inadequacy of globalised internet technology is a sign of super-colonialism in our times. In this document, we provide insights to some of the observations focused on fundamental technical misalignments, as they are harvested from operational research in our rural environments. We endeavour to formulate integrative narratives to breach the disjunct of social and natural research approaches. Specifically, we expose the lack of contextualisation of the Transmission Control Protocol (TCP) and its effect on rural users in Southern Africa.

2 Methodology

This paper is based upon longitudinal, transdisciplinary and mixed-methods research in rural Africa, since 2003. The methods involve Participatory Action Research on internet access and wireless networks since the year 2000 and Extended Case Method analysis and technical laboratory work since 2010 [13,14]. Most of the technical findings in this paper involve retrospective analysis of data from the LinkNet network at Macha Works in Zambia, immersion in rural and urban environments in Zambia, Zimbabwe and South Africa, visits to various (rural) sites throughout Southern Africa, and literature reviews. Also, this paper draws upon laboratory simulations of the behaviour of internet systems in rural contexts. In our ethnographic work, we consider ICTs to interact with multi-level and multi-actor realities. We approach the patchwork of actors and dynamics as being entangled in techno-economic, social and political processes in order to identify issues that warrant exploration. Specific issues, like the quantitative and qualitative analysis of TCP effects, are assessed in reflexive ethnography and lab-based technical exploration.

3 Observations from an African Context

Many persons in Southern Africa lack basic ICT access, especially those at the so-called bottom-of-the-pyramid, as we witness ourselves in our in-situ research. Those in the development-scene (e.g. ICT4D) and in the corporate world (e.g. Basic Access, and Google Loon), often in an Oriental framing [15], seem to regard access provisioning as the last frontier: a market with opportunities for solutions. This battle for the so-called unreached and underserviced rages on. The discourse appears mostly framed in foreign languages with foreign interpretations of values, where renderings of aspects like freedom and democracy are at variance with the community views of the disenfranchised on morality and participation [16,17].

The perception of realities in the lived environment in rural Africa is often far removed from an epistemology that is dominant in ICT producing countries [4,12,18–20]. Andrew Feenberg [21] argues that technologies represent an embodiment of social constructs, created by people for specific purposes. Contemporary practice seems to turn this around: technologies appear to frame our social worlds (cf. [22]). The mobile phone, for instance, has been invasive, constitutive and transformative in Africa (cf. [23]). Kentaro Toyama [24] gives vivid descriptions of how ICTs force local world-views, concepts and meanings to interact with foreign concepts and expectations framed in foreign philosophies, concepts and language. Therefore, those dwelling outside the technology producing centres must cope with technology developed in an extant framing. Tim Unwin, David Nemer, and others give heed to the underlying clash of paradigms that results in widening digital divides and digital exclusion [18,25,26]. Nicola Bidwell [27] shows how the continuation of a history of colonialism and meanings embedded in ICTs is disruptive to local communication practices and results in a disconnect that reifies knowledge, disembodies voices and neglects established rhythms of life in an African village. Through ICTs, African communities interlink with a dominant, Western-centric view of the world, without—as Mark Graham [28] shows—much local content to interact with. In previous work analysing the network traffic in LinkNet's network in rural Macha, Zambia, we showed that most traffic in Macha remained within the village [29]. Also, we showed how the cultural challenges amalgamate with environmental constraints such as for electricity supply and other supply chain logistics and skills constraints in support of local ICT practitioners [20,30].

Within what Galtung [31] calls 'center-countries', especially in its centres, perceptions of internet performances seem positioned as being 'uniform'. Such uniformity implicitly assumes the availability of high quality bandwith options, relative low latencies, and an abundant electricity supply [32]. However, outside this realm, in so-called 'periphery-countries', especially in the periphery of the periphery-countries, realities are more diverse, with bandwidth options low, latencies high, and electricity in short supply.

Sabelo Ndlovu-Gatsheni [33] shows how Africa harbours multiple, competing world-views. We recognise a highly varied dialectic where multiple world-views and various positivist and interpretivist approaches compete. As a result, African practice often contends with many definitions and meanings expressed in the same continuum [18,34]. In the use of technology, these various ways of understanding come to loggerheads. Most technologies are created in a culture and context foreign to the African settings. Susan Wyche [35] shows how users long for contextual designs, and have their inputs ready. However, the culture and context of technology producing areas have particular—often oriental [36]—views on how to regard human needs [37] and others [38]. In short, orientalism combined with imperialistic practice has left its African legacy through the practice of colonialism [39]. Current coloniality in both the center and the periphery is the remnant of a history of domination, exploitation, and othering [40]. Paul Dourish and Scott Mainwaring [22] argue that the contemporary ubiquitous computing practice aligns with such a colonial intellectual tradition.

The facilities of ICT—both in their positive and negative aspects—are a most significant fact of life in the current time frame and in the global village. The technical performances of computer operating systems, network access points and internet connectivity are framed and chained as per Open Systems Interconnection Model (OSI Model), each layer and its interconnections influence the final usability by technology users. Long-term experience and observations of the introduction and growing presence of ICT in rural environments in Southern Africa sensitised us to the complexity of issues involved in this myriad of social realities and varied understandings. For instance, we recognised how technical nomenclatures and a whole range of methodologies result in a myopic understanding [9,12,18,19]. It is in the actual use of ICT within African environments that the sheer complexity and mismatch of the design and practice comes to the fore [8,19,29,41,42].

3.1 Technical Shortcomings in Rural African Internet Networks

In our daily practices in South Africa, Zimbabwe and Zambia, and during travels on the continent interacting with Africans outside of the metropolitan, we encounter an unabated stream of dissatisfied users of internet access, network services and applications. Although apportioning of guilt is not common in most African cultural expressions [43], the users we met invariably complain of a *slow internet*. Whatever the case, whether ageing or new computers or advertised high or low bandwidth network access connections, users in disenfranchised areas invariably report anecdotes of experiences that feature 'slow or no response', using devises and applications connected to the internet. These complaints remain anecdotal, as there is a general lack of elongated academic research, respectfully situated within disenfranchised areas in Africa. In our research, we have quantified the complaints in the case of the LinkNet network at Macha Works in Zambia. We concluded that, indeed, the internet can be labelled as slow, due to issues with TCP in high delay networks [8]. We observed that service interruptions are regularly experienced with video streaming, store and forward services, embedded services, banking applications, office software, among others. Also, as the applications go through frequent patches and upgrades, the user experience for the same application can change from version to version.

The persistence of the complaints over the years amazed us; this does not align with an Africa generically framed in a narrative of explosive growth, linked to the world with an ever-increasing amount of cables and higher speeds. Although we spend much collaborative effort in longitudinal research and development to facilitate contextual embedded network access for over 10 years, with community deposits of information and international academic scrutiny [13,14], the complaints remain.

We notice a continued reliance on mixed and ageing networks (GPRS, 3G, Very Small Apperture Terminal (VSAT), varieties of WiMax and multi-hop links) with poor performance aggravated by an installed base of older computer systems, relative low-grade devices, and a growing share of web-interfacing and cloud-based services [44]. An average web page size in 2012 was 68 times larger than the average size in 1995 [14, p. 86]. The inequality in the availability of bandwidth has grown three-fold in the last 10 years [7]. This is further aggravated by a growing populace accessing the internet. We conclude that there remains a defacto constant: rural networks feature congestion, high latency and poor throughput or a complete lack of availability.

3.2 Performance Deteriorations Inherent to Contemporary Transmission Control Protocol/Internet Protocols and Services

Our investigations centered on the shortcomings of the end-to-end connectivity provided by the Transmission Control Protocol/Internet Protocol (TCP/IP) and the performance of Directory Name Services (DNS). These protocols and services are among the basic building blocks of the internet. Due to the general constraints of doing research in rural areas, mostly devoid of financial or research resources, we relied on the opportunistic use of facilities, wherever and whenever available. Our first findings were presented at the Africomm conference in Cameroon, in 2012 [9].

Among the main technical hurdles remains latency [8]. Latency of at least 400 ms is introduced in case satellite connectivity. This latency is unavoidable due to the large distances between a geo-stationary satellite and the connectivity hub, due to multi-hop environments, and the frequent use of low-grade equipment with large buffering and processing-time overheads; In rural Africa, one finds all kind of equipment, including poor quality hardware platforms and devices, often with outdated and unpatched software [45].

Recently, Zaki et al. [46] confirmed our suspicion of the significance of the problems that result from the architecture of Directory Name Services (DNS). In previous work [9], we quantified the poor performance of TCP outgoing links on the Windows operating system compared to other Operating Systems (OS) such as Linux and MacOS in the LinkNet network in Zambia. Subsequent simulation in lab-environments confirmed the significant negative effects of high network delay on Windows 7 and XP machines; internet throughput in these Windows OS is unfairly disadvantaged and this effect is amplified even further when there is a mix of Windows and Linux flows present. The simulation made use of a Windows or Linux virtual machine connecting to a Linux Virtual machine over a simulated 1 Mbps link. Table 1 presents these results for a network without delays and a network with an introduced delay of 1 s. The latter is a typical delay we observed on the satellite network during peak usage periods.

Table 1. Simulation results showing TCP/IP throughputs for Linux and Windows flows in a network, single and mixed.

No delay introduced (10 ms systemic delay)	
Linux TCP flow only	892 kbps
Linux TCP flow with Windows flow added	822 kbps
Windows TCP flow only	968 kbps
Windows TCP flow with Linux flow added	151 kbps
With 1 s delay introduced	
Linux TCP flow only	860 kbps
Linux TCP flow with Windows flow added	858 kbps
Windows TCP flow only	110 kbps
Windows TCP flow with Linux flow added	57 kbps

Further investigation from 2014 until 2016—with the help of engineers at Microsoft Research Laboratory in the USA—exposed the underlying cause of the problem. Windows 7 and Windows XP use a default TCP receive-window of 16 kB while the receive-window 'auto-tuning' is disabled by default. For a 1-second link delay, the result is a maximum throughput of 16 kB $\times$ 8 bits/1 s= 120 kbps. This is similar to the 110 kbps seen in the simulation. Linux, on the other hand, has a default maximum TCP receive-window of 128 kB. This results in a maximum throughput of 128 kB * 8 bits/1 s = 1,024 kbps. Furthermore, Linux has the receive-window 'auto-tuning' enabled by default.

Even upon enabling the default receive-window in Windows or enabling its auto-tuning, the TCP protocol—TCP New Reno, used by Windows 7—uses a delay-based congestion-window that adjusts throughput according to the Round Trip Time (RTT) of the last TCP packet. This makes Windows more sensitive to high delays. Linux, however, uses a different version of TCP—TCP CUBIC—that changes its congestion-window on the basis of the last occurring congestion event. As a result, Linux is less susceptible to high delays. Further investigation with Windows 8 and Windows 10 OS showed that these operating systems use the same conservative default TCP values, although they use a slightly improved TCP protocol called TCP Compound.

Modern satellite networks make use of TCP acceleration techniques, so-called TCP proxies. These proxies are implemented in the satellite modems and blur the distinction between the performance of Linux and Windows. These acceleration techniques create a virtual version of the network end-point on the client side of the satellite modem in order to cause the network to rapidly increase the TCP congestion-window and hence accelerate the throughput of the upload. However, our experiments throughout Southern Africa confirmed the issues resulting in poor performance of outgoing traffic for Windows OS persist in GPRS/Edge/3G networks as well as multi-hop wireless networks and legacy satellite modems.

The described findings affect outgoing connections only and hamper user experiences when using the internet, particularly severely when doing cloud-service uploads or using VoIP services. We observed frustrated users when they did try to upload data or used VoIP services like Skype, on Windows machines. Some users in LinkNet network became hostile to the LinkNet support staff, upon the suspicion that they were deliberately slowing down traffic for users using Windows computers compared to users utilising Apple computers or other Linux based OS, like Ubuntu. This suspicion persisted, even though the logical and technical explanation for the experiences where explained by engineers.

With Windows being the dominant OS in Africa—there are lots of legacy systems based on widely available copies of Windows-XP or Windows 7—the compromised performance of Windows' TCP/IP implementation is a significant issue. This problem is compounded by the fact that TCP/IP is continuously being developed for improved performance in high-bandwidth networks [47], potentially creating further difficulties for 'slow' networks.

In further research, we confronted the assumption of always available affordable bandwidth for Operating Systems and Applications-updates on computers, phones, tablets and other computing devises. These updates use precious data, depleting users' data-bundles. Updates often start/stop and restart due to poor and failing data connections [8]. Users are confused because their data is used up by a process that they had no control over. We noticed that standard web proxies which could cache these updates are either not in place or are not configured correctly to be able to cache update file types. For example, the squid-proxy requires an additional entry to match .cab, .msi, .exe and .apk file types for updates. Even when the additional entries are in place, sometimes delta-updating used by some update processes will cause a cache to miss. To solve the problem of updates consuming user's data, modified and smarter caching at the internet gateway is required. Such caching stores popular updates. Possibly, public wireless access points could be placed in various places where connectivity is challenging to provide users with a local update for their device. As to make the case for more localized caching and clouds (cloudlets) to support the strong locality in the network, we developed VillageShare to allow local users to share content with each other locally without use of the internet connection beyond the gateway [44].

4 User Experience Compromised by Misaligned Internet Technologies

Technology research tends to build upon a perspective derived from research localised in center-countries [18, 19, 36]. Therefore, the average network performance and user experience observed in such environments pan out in the design and generic settings of software. In such relative affluent areas, in general, users are connected to low latency networks with relatively high speed connections with cloud-servers geographically relatively close-by.

Browsers like Google Chrome are set to show a web-page when all components of the web page have been received. In the Southern African environment, this means that frequently more than 10 s pass before the first information appears on the user's screen. The user calls this 'slow internet', although the actual transfer speeds might be relative high.

Web-pages embed calls for content from many different sources. Each call involves a DNS request and due to many requests, the time for the electronic signals to travel the physical distance to far-away servers, and the computing processing times, significant delays are a natural phenomena.

Cloud-services necessitate the information to travel vast distances, even if the recipient of the information is in the same community. Therefore, cloud-services add to the challenges in usability and user experiences in Southern Africa. Many internet services and products such as Google and Facebook, restrict access to a secure version of their web sites. This adds further delays to the web experience of users in Africa due to the need for requesting and processing of security certificates.

Google has set its services to time-out after a (perceived) lack of response from the client to prevent too many hanging connections. Web browsers also have default time-out values and keep-alive values. By default, these are set for typical Western networks with low latency. Due to the physical distance of Southern Africa to many network servers with the requested data, these default time-out settings can cause web pages to respond with a 'timed-out message'. In a VSAT environment, high latency is a natural given en latencies above 1 s are common. In a congested network using a satellite connection, these delays can be higher than 10 s [8, 46]. Time-outs in services cause frustration and wasted internet expenses.

News applications, video applications, and software like Microsoft Office365 appear to have embedded protocols with various and non-standard time-out settings. If one of these settings times out before all interactions are finished, the user will not receive the service requested. The behaviour of the application thus cannot be relied upon. For instance, a time-out of a user licence check can disable Office365's ability to save ongoing work. In general, designers in bandwidth rich and latency low environments do not necessarily design their systems to allow local customisation and optimisation for users in bandwidth constrained and high latency environments. The fall out of these issues are real; Relationships in communities suffer, as performance differences motivate community members to accuse engineers of unfairly disadvantaging specific users.

Technological representation Mis-aligned with Language in Southern Africa
'This internet is slow' is a general statement, understood by many on the African continent. This statement, however, does not necessarily translate well into a cause and effect designation addressing the underlying issues. The technical nomenclature provided for by the (foreign designed) systems and the labelling they represent do not align with a local/African nomenclature of technology. In Southern Africa, the Bantu family of languages has a different representation of concepts. Languages tend to refer to living and movement, while European languages refer to things and allow for a deconstruction of realities [48,49]. Therefore, there appears no relationship to the (wording of) the Southern African user experience and what is needed to communicate with designers to improve the system (cf. [27,50,51]). A tool-set or an automation of context-adapted tests for adjusting application settings according to the particular link-specificities is not available. In February 2016, in Harare, a Shona speaking ICT-expert working in rural areas in southern Zimbabwe told one of us: "When I explain my mission, I find myself unable to translate English words like 'web-page' or 'application', thus I switch between Shona and English. However, my audience, with whom I wish to develop an application, does not use English much. They appear not to comprehend these English words."

The inter-cultural mix of meanings does not translate the user experience from African users into a language that the designing engineers—mostly in other environments and context—can understand. An engineering not geared for the Southern African reality and its social constructs, dis-empowers African engineers to engage with these challenges [12]. This dis-empowerment fuels an imperialist/colonialist narrative embedded in a White Saviour Syndrome, vocalising the need to 'bring technology' for the benefit of 'the other' [36,52]. As a result engineers from technology producing countries feel sanctified to fly into Africa for research, training and 'to solve issues', as technical assistants. Only when engineering companies engage meaningfully with African realities, empowering indigenous research and development in (rural) Southern Africa, can this disempowering spiral be broken [12,18].

ICT Standards Insensitive to Location and Community Contexts
As the dynamics of a networked society aids the centralisation of power, it needs a conscious effort to guard the ethical principles of neutrality, non-discrimination, equity, and reciprocity. All involved in the value chains of ICT production need the capacity to communicate over the various divides that separate people. Reflecting on an African value as Ubuntu, this can involve catering for shared identities and communal love [53]. Driven by its moral value, in general, African engineers aim to withstand the drive of self-aggrandisement and to assure a truly global and diverse community of all stakeholders and interlocutors [20]. Incorporation of previously disparate views, e.g. through listening to the subaltern, is the future source of corporate (= incorporating all) development, social responsible behaviour, and just and sustainable progress.

We see some hints of incorporating a localisation aspect in the operations of technology. For instance, Google provides for browsing on slow links in Gmail, allowing access to a less-complex web-interfacing. True localisation needs development and testing on site and in context, in an African laboratory and/or community, to see if the OS/application/hardware is truly globalised. To our knowledge, such a laboratory does not exist. Such a technical laboratory should operate in real-world, main stream (rural) African conditions, incorporating real challenges of electricity, connectivity, environment and business context in their daily operations. Many developers appear to 'have heard about Africa', but are void of an embodied experience of African contexts, meanings and effects over an extended period of time.

In an effort to alleviate the TCP/IP disadvantages in Windows and other highlighted problems, we propose that standards be developed to allow operating systems and protocols to query or check the context and assess if the system is connecting over a relatively slow/high delay link. Upon understanding the context, the technologies, such as operating systems, can evoke a contextualised TCP/IP, DNS caching, and web browsing.

Shortcomings Invisible for 'Out-of-Context' Research and Development Many 'cause-and-effects', in reality, involve a complex chain of events. Due to the shortcomings of globalised internet in Southern Africa, the regular short-falling of realities with respect to promised user-experiences challenges the chain of engineering causes—in this case, poor TCP/IP performance, and DNS induced delays—, the performance of low grade equipment, and the underlying designs. To gain an understanding, one must be able to switch between paradigms, as they present themselves in the various parts of the world [18]. The ultimate cause of the shortcomings, we claim, is the exclusion of the voices from so-called non-technology producing countries, especially from Sub-Saharan Africa. This major omission leads to unlinked, uncontextualised and ultimately unsuitable technologies in Southern Africa. Soliciting complaints from individual users does not solve this conundrum, as such practice does not align with many cultures in Southern Africa [20, 53, 54]. However, the daily user experience of users in Southern Africa is consistent, albeit at variance with what users in affluent geographical areas might experience. Even the meaning of terminology like ICT or internet might be at variance, e.g. Facebook can be regarded 'the internet', with the complex aspects of coloniality playing subversive roles [33]. Thus, there are many variances and aspects influencing perceptions of understanding of causes and effects that inform the shortcomings of globalised internet in Southern Africa.

Learning from the experiences of an international health research centre situated in rural Macha, Zambia, and research at Macha Works in the same community, we experienced the benefits of research facilities to research, design and test technologies in context. Initiatives like Living Labs are promising in their efforts to circumvent the trap of localised activities being determined by a distant centre [55]. For truly globalised technologies, it is important to come to terms with, and incorporate, the diversity of contexts and experiences. We need a global understanding of a locally embedded, healthy ICT systems, in the same way that we need a locally embedded, healthy healthcare system for communities and people.

5 Conclusion

This paper gives examples of how major components in contemporary Information and Communication Technologies do not align with an African context and disenfranchise the Southern African user in ordinary circumstances. Although most users rely on such technologies to participate in a globalising world, the paper shows how the basic networks building blocks provided do not perform well in Southern Africa. Major applications, such as leading operating systems, do disenfranchise the Southern African user. More so, the paper shows how language, standards, and paradigms are major hurdles to learn from the user experience in Africa.

The impaired TCP/IP, DNS and web browser issues coming to light in Southern Africa are a general issue of the failure of global non-localised technology. Contemporary technologies fail to incorporate all experiences, perceptions and human intents, in an inclusive manner.

This paper poses the quest of changing the engineering attitude from considering technologies useful to Southern Africa to an attitude of developing technologies with Africa. Globalised technology would be sensitive to its context and is not 'one size fits all'. Apart from the obvious need to address current shortcomings in network protocols, operating systems and software applications, the paper calls for contextual Africa-based engineering research and development to ensure the development of network protocols and applications that are context-sensitive, adaptive and truly global.

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