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Ten Years of Live Video Streaming Experience in Kenya

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Abstract
Live video streaming can deliver live events such as instruction, webinars or meetings without the need to travel to the event venue. This case study consisted of ten years of live video streaming experience principally from sites in Kenya starting May 2010. Key challenges and lessons learned were identified as the telecommunications infrastructure in Kenya developed over the years starting with 2nd Generation services. The key initial challenge was to identify suitable Internet service providers who understood the requirements. The cost was initially high approaching US$1,000 for a three-day event in 2010 but dropped to about US$20 in mid-2019 with the use of 4th Generation wireless routers. Technical challenges to live streaming included buggy modem drivers, unreliable 4G coverage and interference of encoding software by other software such as web browsers. With good 4G coverage, 1040p High Definition (HD) quality was achieved which is adequate for most live streaming applications.
Keywords: *Live video streaming, streaming media, developing nations, Kenya***.**

1. Introduction

Video has become increasingly dominant as a key contributor to Internet traffic. Cisco, the leading provider of networking solutions, estimates in its trends report [1] that by 2022, the global IP video traffic will be 82 percent of all IP traffic (both business and consumer), up from 75 percent in 2017. Of particular interest for the researchers in the study reported here, are the technical challenges of live streaming video delivered via free video streaming sites such as YouTube.

As streaming video becomes easier to use, it is expected that many organizations will start to use the media for broadcasting their content. The authors are particularly interested in broadcasting live content from challenging open-air sites in Kenya in order to acquire experience regarding the challenges that must be overcome to allow acceptable live streaming from these environments.

The live video streaming event were carried out from several cities and towns in Kenya over a ten-year period. One broadcast was carried out in Luanda, Angola. The work was carried out over a period of ten years starting in May 2010. Professional live broadcast equipment would have cost hundreds of thousands of US dollars which was out of the reach of the researchers, hence, open source or free tools were preferred. Internet-based live streaming was selected rather than the more reliable but very expensive direct broadcast via Very Small Aperture Terminal (VSAT).

The steaming events were open air meetings conducted by Prophet Dr. David Edward Owour who was sent to prepare humanity for the return of the Messiah. His meetings are very large with millions of attendees and provide very challenging conditions for live Internet video streaming attempts. There were varying degrees of success depending on a variety of factors as reported later in this article.

Because live video streaming via the Internet in semi-rural environments in a developing country situation is a relatively recent phenomenon, little has been reported about experiences with streaming in these situations. The goal of this case study was to record experiences with live video streaming from open fields in semi-rural developing country environments. The case study's objectives were to establish the available connectivity in these locations, identify the key hurdles to live streaming and identify the quality of streaming that can be achieved from these locations. Because the events occurred over several years, the case study also provided the opportunity to record the changes in the telecommunication environment in the country over the ten years.

2. Literature Review

The Covid-19 has had significant impact on live video streaming trends worldwide. The Covid-19 lockdowns that were introduced in many countries forced a lot of workers to work from home and schools and colleges to go online. Videoconferencing traffic increased as much as 700% on some networks. After the strict lockdowns were eased, livestreamed content such as videoconferencing remained elevated suggesting that it may not return to pre-pandemic levels. Content providers and network service providers have been forced to rethink their architectures and strategies. The trend seems to require an expansion in the role of Content Delivery Network [2].

The changes to the workplace and learning brought by the pandemic have highlighted challenges to live video streaming. Live video streaming has been transformed from a convenience or novelty to a necessity. Broadband access becomes a prerequisite to participate in live-streamed meetings and online classes [3]. [4] identified several challenges to online learning. Among them organization of work processes and time management; shortage of gadgets and crashing systems; connectivity and limited computer literacy. Students may fail to join an online class because they cannot get sufficient bandwidth. Emerging needs have made broadband-for-all a part of critical infrastructure in the 21st century [5].

Live video streaming has found increasing applications in education, health provision, and social activities. Restrictions on gathering during the Covid-19 pandemic has made streaming a necessity at social and religious events; meetings; school and college classes; political events; TV journalists reporting; family events; and virtual healthcare visits. It is clear that live video eliminates barriers of distance and space. A live streamed church service can host thousands of participants across the world and allow simultaneous interpretation in several languages. Online live tutoring can accommodate thousands of students and, hence, help reduce costs per student and access to gifted teachers without the need to have costly face to face interactions. Such arrangements helped to reduce educational disparities that disadvantaged students from humble backgrounds in China while advantaging students from wealthy backgrounds who could afford private tutors. In the case of health education, live video streaming has allowed specialised training across wide geographical areas at very low or negligible cost to the trainees. As an example, microscope adapters for mobile phones allow a specialised trainer to capture and display images to trainees giving access to content that would be difficult to access using traditional instructional methods [6][7][3][8]. However, effective use of online learning requires enhanced ICT and other skills. [9] found that switching to online learning presented challenges to instructors. The new teaching environment requires additional technical, managerial, instructional, and psychological skills.

In many parts of the world where healthcare is not well-resourced, telehealth can open up new opportunities to improve healthcare provision. As already mentioned, microscope adapters for smartphones can be combined with live streaming to access expert diagnosis via a consultant located remotely. Mobile phone-based diagnostic tools are likely to become more accessible. They offer advantages of relatively low cost, ease of use and field portability because many are pocket-sized devices. However, deficient broadband infrastructure and shortages of consultants to analyse the large number of generated samples may limit the use of such diagnostic tools. Crowd sourcing methods and machine learning approaches are suggested as ways to deal with some of these limitations [10][11].

Quality considerations can affect the viability of live video streaming. Video quality is still the top consideration among live video streaming users. Latency or delay is the second most important consideration. In live sports, as an example, if the latency or delay in a live streamed event is more than about 5 seconds higher than the live TV version, it degrades the viewer experience. In video-assisted surgery, latency issues become crucial considerations. Military applications of live video streaming present even narrower latency tolerances. Going forward, there is interest in streaming technologies that minimise streaming latency while maintaining high video quality. During the Covid-19 lockdown in Europe in early 2020, content providers reduced video quality from High Definition (HD) to Standard Definition (SD) in order to prevent network bandwidth capacities being exceeded by demand. It means that high video quality directly impacts bandwidth demands which in turn may overwhelm networks that were not designed to handle surges in demand. [2][12][13].

A key trend in streaming architectures has been the increase in the use of Content Delivery Networks (CDN). In 2009, CDNs handled less than 25% of the total Internet traffic but by 2019, they were handling close to 90%. CDNs work by placing content caches closer to the customer. In many cases, these caches are within the service provider’s network, the so-called on-net cache. Typically, these service providers are mobile 4G/5G telephony-based broadband providers or Fibre To

The Home (FTTH) providers. However, during the Covid-19 pandemic, these on-net caches were overwhelmed by the demand forcing many content providers to provision directly from their data centres. The experience during the Covid-19 lockdown suggests that CDN caches do not have sufficient surplus capacity to handle peaks such as the one triggered by the Covid-19 pandemic [2].

Streaming protocols in the 21st century have evolved as end user demands and network performance considerations change. On the user end (or egress), there has been a change from proprietary to open standards and from stateful to stateless protocols as well as migration from protocols that require specialised servers to those that rely on existing Hypertext Transfer Protocol (HTTP) servers. Concerns about widening the network risk footprint by use of uncommon network ports has also encouraged use of HTTP which use ports 80 and 443 (HTTPS) for ordinary web traffic hence easing firewall configuration and shrinking the attack surface. Further, older live streaming protocols such as the Real Time Messaging Protocol (RTMP) though offering relatively low latency and support for popular audio and video codecs, were not optimized for quality of experience or scalability. Moreover, HTTP-based streaming eased caching on CDNs which increases their attractiveness. Today's HTTP-based protocols use adaptive bitrate streaming which adopts the stream bit rate to the network condition which greatly reduces buffering and improves CDN caching efficiency [14][15][16][17].

On the ingress end where the encoded video stream from the source enters the streaming servers, RTMP has persisted and has only recently started to be replaced by newer protocols such as HTTP Live Streaming (HLS), Secure Reliable Transport (SRT), and Dynamic Adaptive Streaming over HTTP (DASH) that offer wider codec support including the H.265 and VP9 that support 4k streams. Additionally, there is greater agreement to adopt a common container format in the streaming workflow with the Common Media Application Format (CMAF) as the standard based on the fragmented MP4 container. MP4 is the Moving Picture Experts Group (MPEG)-4 Part 14 specification. Before CMAF, streaming service providers were forced to present multiple container formats because Apple HLS used a different container format from MPEG-DASH which the rest of the world has adopted. Essentially, this requirement multiplied caching and transcoding costs [18][14][19][20][21].

In developing nations, there is a race to expand access to the Internet and improve existing service quality. Facebook is building 2Africa, a 37,000km undersea cable around Africa that is expected to provide nearly three times the total network capacity of all the undersea cables serving Africa today. Providers are starting to roll out 5G and increase 4G access in areas previously underserved by mobile broadband. Facebook estimates that only about 25% of the people in Africa have Internet access so there is a lot of growth potential on the continent [22][23][24].

The global nature of streaming services such as Youtube means that legal issues can be quite challenging for end users to handle. Youtube, whose offices are located at 1600 Amphitheatre Parkway, Mountain View, CA 94043, operates under the laws of the state of Delaware. Copyright matters in the USA are handled under Section 512 of the 1998 Digital Millennium Copyright Act. Within the USA, there has been dissatisfaction with the operation of Section 512. Therefore, with the changing ecosystem of the Internet in the intervening 22 or so years since this law was established, the USA has seen it fit to examine whether Section 512 is adequately serving its original intent. The matter of how to manage online intellectual property issues and disputes in such an environment is not likely to be resolved soon. In the case of YouTube clients, outside the USA take-down requests under Section 512 generates vexatious court cases within the end users' jurisdiction in their countries of domicile [25][26]. In the case of Kenya where the case study that is the subject of this paper is located, copyright law is still in its infancy and cannot adequately handle the emerging issues related to online copyright disputes [27].

3. Case Study Environment

The live streaming environment was in most cases an open-air location, often a stadium or open field, in which a very large number of people were gathered for a meeting typically lasting three days. The streamed signal consisted of Standard Definition (SD) or HD video tapped from a fixed camera running for several hours during the day and sometimes during the night. The video was combined with audio from the public address system. The audience was in several nations around the world watching via a video player embedded in a web page set up for the purpose. In all except one case, free live streaming sites were used.

The initial equipment used for streaming consisted of a basic notebook computer with a 2.20GHz dual-core processor running Windows 7 with 3 GB of Random-Access Memory (RAM) and 250GB of hard disk space. It had a Windows Experience Index of only 3.4. The current version of Windows (10) no longer includes the Experience Index. Video capture was achieved using a Pinnacle MovieBox 710 and 510. At the beginning, several streaming software and live streaming sites were tried out. Eventually, Ustream (now IBM Watson Media) was selected as the most attractive live streaming site while Adobe Flash Media Live Encoder (FMLE) was selected as the encoding software. The reasons for this selection are reported later in this article. In the last three years of the study, YouTube Live streaming was used due to challenges that emerged with Ustream services.

3. Method

The researchers were not responsible for selecting the geographical sites from where live streaming was done but were responsible for providing live streaming services to the meetings led by the Prophet. This arrangement had the advantages of providing real-world situations but the disadvantage that site selection was not within control of the researchers. During the period of the tests, these meetings were held at the following towns and cities (the number of meetings held at that location is shown in parenthesis): Eldoret (2), Kakamega (2), Kericho(1), Kisumu (3), Kisii (1), Mombasa (2), Nairobi (5), Nakuru (10+), Nanyuki (1), Nyeri(1), Thika (1) and Luanda (1). All of them are located in Kenya except Luanda which is the capital city for Angola. In the initial three years, available Internet service providers were contracted to provide a temporary 1 Mbps symmetric Internet connection as per the specifications provided by Ustream, the steaming service provider at that time. The first three tests were carried out at Nakuru town where the researchers are based and where most of these meetings were held. At the beginning of the tests there were two service providers (we shall call them Company K & Company T) with infrastructure covering Nakuru town but only Company K was able to offer a connection to the location of the first live-streamed event using Worldwide Interoperability for Microwave Access (WiMax)-based package through a third-party agent. Company T introduced a Code Division Multiple Access (CDMA) Evolution Data Optimized (EV-DO) service that was used in Kisii town in 2011 with good results. Towards the end of the first series of tests, Company T had introduced a 3rd Generation (3G) High-Speed Downlink Packet Access (HSDPA) modem service which outperformed Company K’s services in every respect. However, this service covered only Nairobi, Mombasa and Kisumu but not Nakuru. After the introduction of CDMA EV-DO and 3G HSDPA modems, the use of WiMAX radios was discontinued. The last open-air live-streaming test was carried out in Nakuru in August 2019 using a 4G wireless routers and Speedify, a link aggregation tool. Since the Covid-19 pandemic begun, open-air meetings were discontinued but regular, thrice a week church services were streamed live from a fixed location in Nairobi city.

The objectives of this study were to document the experiences of live-streaming video from various open-air locations in Kenya and to identify the key challenges to such streaming as well as lessons learned. Additionally, the case study sought to document the change in live-streaming outcomes across geographical locations and over time. Where possible, a site survey was done some weeks before each meeting and a tentative location for the equipment selected. In most cases during this initial phase (three years), a WiMax radio was used. The streaming equipment needed to be within 100 metres of the WiMAX radio because they were connected via Unshielded Twisted Pair (UTP) cable which has a segment length limit of 100 m. The WiMAX radio needed to have line-of-sight with the WiMax hub or base station. In some locations, such as Nyeri and Kericho, line of sight was not possible to achieve due to the terrain. In most cases where streaming was done from open fields, the equipment was located in the rear portion of a 62-seater bus in which a few seats had been removed to create a kind of mobile broadcast studio as shown in Figure 1.

Figure 1: Live-streaming “mobile studio” in rear of a 62-seat bus

Electric power was provided from the power grid but a standby generator was available for the meetings. However, it was essential to provide an Uninterruptable Power Supply (UPS) because some of the equipment, notably the WiMax radio and the router were delicate equipment likely to be damaged by voltage fluctuations and spikes. Standby generators were particularly prone to voltage instability and resulted in at least one instance to serious damage to the public address audio amplifiers.

The audio signal was tapped directly from the public address system mixer using a coaxial cable about 60 metres long. At the start of the tests, the intention was to capture video from a mobile camera using a wireless video transmitter operating in the 2.4 GHz industrial, scientific and medical (ISM) band but the device did not function as expected. Therefore, the video signal was tapped from one of the fixed cameras which had a composite video port using a 70 m coaxial cable. Both audio and video cables were terminated at an active 4-output splitter which supplied video and audio signals to the broadcast and recording computers as well as to outdoor LED screens that provided viewing for the very large overflow crowd. From this splitter we had the audio and video signal carried to two Pinnacle MovieBoxes (model 710 and 510) on to the broadcast and recording computers respectively. Figure 2 is a simplified illustration of the initial set up of the streaming station. The recording computer was included later when we realized that the live streaming site’s recording facility was unreliable and difficult to manage. Video was recorded for later upload to YouTube (“repentancechannel” and “repent and prepare the way” channel).

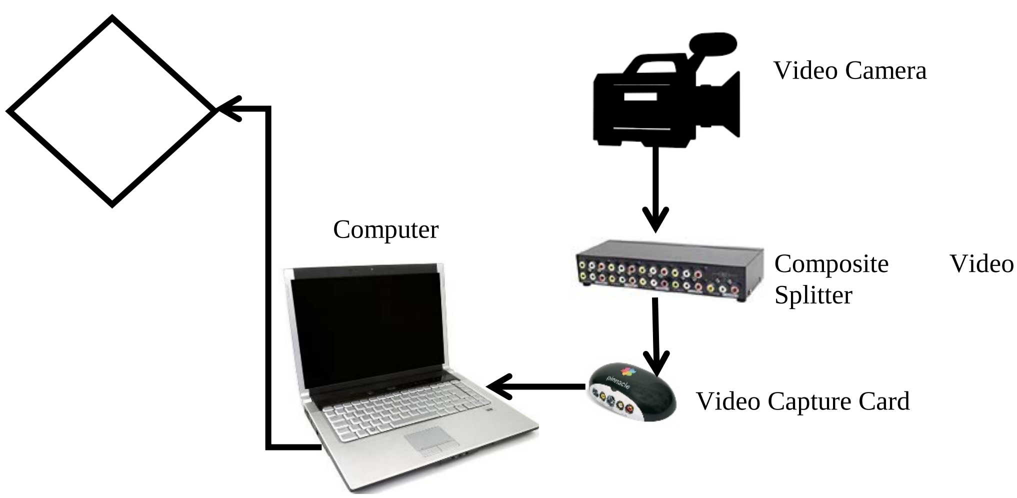

Figure 2: Simplified initial equipment layout diagram

Note: Later, composite video input was replaced with SDI and WiMAX with 4G link aggregation. The video splitter was replaced by a video mixer.

Cables were buried about 10 centimetres underground to protect them from interference by the very large crowds. Burying was possible because the meeting grounds were covered with grass and earth. There was, however, risk from other cable installers and incidences of cable cuts were recorded. While cut electrical cables can easily be joined, cut coaxial and UTP cables cannot be repaired without considerable deterioration of signal quality.

At each site the router, where used, needed to be configured. A Cisco wireless router WRT150N was initially used because it was very light and easy to use with built-in Network Address Translation (NAT). In addition, it has a built-in four-port switch and access point all in one. Its main shortcoming was the absence of Simple Network Management Protocol (SNMP) which meant that it was difficult to use the traditional tools such as bandwidth monitors in the router. This inability meant that it was also difficult to demonstrate the shortcomings of our Internet connections to service providers. Once WiMax was discontinued and 3G/4G adopted, simple wireless routers were used to connect to the Internet. In later years, new monitoring tools, such as Glasswire, became available that did not require SNMP configuration.

4. Results

Extensive experience was gained with live video streaming over a period of ten years from varying locations. Some locations were in the midst of major towns, others were on the outskirts. In one case the streaming was carried out from two locations in Luanda, Angola. Some of the terrain and locations were friendly to operate from and some was quite hostile.

4.1. Internet Connections

The most challenging hurdle was to obtain a stable Internet link, that is, one that provided a stable minimum bandwidth sufficient for carrying the broadcast signal. During the first two attempts both of which were held at Nakuru in May and November 2010, it was found that the Internet speeds attained were far below the contracted speeds and, further, were unstable. The ideal speed was 1 Mbps based on Ustream's recommended upload speed of 700 kbps for good quality streaming in 2010. However, 300 kbps could barely be attained for an extended period. Considering that the meeting went on for three days non-stop, stability was important. Later research established that, with the right tools, it was possible to broadcast live video at 200 kbps though with greatly reduced video resolution.

When arranging to broadcast in the third meeting that was to be held at Kisumu on the shores of Lake Victoria in August 2010, we discovered that our third-party network providers may not have been providing services with approval of the infrastructure owner. Indeed, they seemed to have offered what is known in Kenya as a "shared link" meaning that several customers were sharing that channel for their Internet services. The converse is a dedicated link in which, supposedly, one client has monopoly over the leased channel.

A new service provider, this time an established retail provider, was selected at Kisumu. Company K was still the infrastructure owner, but they had no retail services for small customers at Kisumu hence services were purchased through their retail wing which we shall call SG. Company T was unable to provide services at Kisumu. At that time, Company T offered Asymmetric Digital Subscriber Line (ADSL) services that required a copper circuit to be physically present at the site. There was no such circuit at Moi Stadium Kisumu, the meeting's venue, therefore, they were unable to offer an Internet connection at that location.

The WiMax signal provided by Company K was very strong at Kisumu likely due to the flat terrain and the proximity of the WiMax hub which is within the city's central business district unlike the case of Nakuru where the WiMax hub was atop the nearby Menengai crater about 5 km away. The target speeds were achieved at Kisumu. However, network stability was not attained because, on the last day of the meeting, network connectivity was lost entirely due to what we were told was a fibre cut in Company K's network. This was the first of a series of such questionable "fibre cut" incidences.

In December 2011, a meeting was to be held in the Bukhungu Stadium at Kakamega town located in western Kenya. Though Company SG informed us that there was connectivity at the site, it was discovered later that the hub at Kakamega was not WiMax but the less powerful "VL" (believed to be a Alvarion's BreezeACCESS VL radio) which operated in the 5.7 GHz ISM band. Further, there were trees blocking the line-of-sight between the stadium and the hub. Worst of all, the hub went off-air entirely and after many phone calls with Company SG's technicians it was discovered that maintenance engineers contracted by Company K had turned off the base station ostensibly for maintenance. In the end, virtually no Internet connectivity was achieved at Kakamega. The facts about the base station being turned off could not be verified. It appeared quite strange that Company K would turn off a hub providing services to the entire Kakamega town and its environs without informing the key retail wing.

The next meeting in February 2011 was at Mombasa next to the Indian Ocean. The situation at Mombasa was much like that at Kisumu where the WiMax hub was located in the middle of the city. The meeting was held at the Tononoka grounds a short distance from the central business district. The two challenges at Mombasa were the tall buildings blocking line-of-sight to the WiMax hub and network instability. The first was solved by requesting the owner of a tall building next to Tononoka to host the customer-premises equipment (CPE) consisting of a WiMax radio. The second challenge was more difficult to solve. A dedicated 1 Mbps connection had been ordered but the link could not attain speeds anywhere near 1Mpbs. One would expect that links in Mombasa were better than those in Kisumu because Kenya relies on submarine fibre optic cables to link to the rest of the global Internet. All the submarine cables in Kenya have landfall at Mombasa. Speeds of more than 300 kbps could not be achieved. The solution was to order a link set to 2 Mbps which raised the link speed to about 700 kbps enough to carry the streaming video. However, the link never really achieved satisfactory stability and there were constant telephone calls with Company SG's technical staff requesting them to stabilize the link. At this point, it started to appear that there were fundamental network design weaknesses within Company K's network. However, Company SG's staff at Mombasa, who acted at the retail wing for K, were so keen to monitor the link and assist that they watched the streamed video during the meeting.

The next meeting was at Nyeri in Central Kenya, a relatively hilly part of the country. The meeting was to be held at Ruring'u Stadium about 3km from the centre of town and about ten kilometres from the VL hub. There was no WiMax service at Nyeri. The situation was like Kakamega where they used a VL radio. At Nyeri, Company SG's site surveyors, who were independent contractors, reported that Internet services were available at Ruring'u. However, when the CPE was brought on site, the signal strength was too weak to sustain a link. Apparently, the site survey had been done on paper not in the field. It was assumed that, if there were existing customers near the stadium, then Ruring'u site would also have access to the radio signal. Eventually, the radio had to be mounted atop a tall tree near the stadium and mysteriously, a relatively strong signal was obtained even though there was a hill blocking line-of-sight to the Nyeri Hill hub (see Figure 3). The remaining challenge was that of network sluggishness where an ostensibly 1Mbps link could not attain this nominal speed in speed tests conducted with the popular speed test sites. Like Mombasa, the company had to boost the configured speed to 2Mbps in order for an upload speed of above 650kbps to be attained sufficient for live streaming.

Figure 3: "VL" radio mounted on a tree in Nyeri Ruring'u stadium 2011.
Note: The radio is the rectangular device atop the thin pole.

The following meeting was the most challenging of all. It was held at Kericho town in the western Rift Valley region between Nakuru and Kisumu. The site survey report indicated that, though Company K offered Internet services at Kericho based on WiMax, there was no signal detected at the planned site of the meeting at Kericho Teacher's Training College.

Company T was contacted and indicated that they could provide ADSL services to the site. However, during the attempt to install the ADSL equipment two days before the meeting, they reported that their network had failed. In the end it was a crisis. A different firm offered to provide services and sent a technician from Kisii who failed to get a signal despite trying out two radios. A second technician arrived on Saturday morning from the capital city Nairobi (the meeting was to start on Friday) and fiddled around the whole day and soon discovered that the CPE radios were not detecting the presence of the base station. It appeared that the base station had been turned off. Tests next to the base station in Kericho town proved this suspicion to be true. The base station maintenance company had to be called in from Kisumu and eventually revived the base station in the late afternoon.

Eventually a weak signal was obtained, and a link set up during the night but in the morning, it seemed that the signal characteristics changed, and it took hours to establish an operational signal. In the end, actual streaming took place for only 1.5 hrs at Kericho. It transpired that the base station had been off for at least a week. This was discovered by accident when a manager at a cooperative society was overheard complaining that his Automated Teller Machines (ATM) had been offline for a week and that he had to contact Company K's directors in order to get help restoring the network. What puzzled the researchers was why Company K would fail to detect that their base station was off or, if they were aware, fail to revive it. When the maintenance company came on site, it took only a few hours to revive and indeed there begun a nagging suspicion that these base station events were not entirely accidental since we were informed that the maintenance company has a visual network display monitor displaying the state of all base stations in real time. It, therefore, appeared that such extended base station down time was either due to incompetence, negligence, or sabotage. This was a danger signal for the streaming team and, at Kericho, the need to seriously consider alternative service providers begun to take on urgency. Unfortunately, the only other viable Internet Service Provider (ISP), Company S, did not respond to our inquiries possibly because we were viewed as a small client requesting temporary services, therefore, not of much financial value to them. At Kericho, it was also discovered that there were "brokers" in the ISP industry capable of intimidating and grossly overcharging clients. Clearly it was an industry in need of serious scrutiny.

In September 2011, a meeting was planned at Kisii and there was real fear that Company K, who claimed to have services at Kisii, would fail. These fears were realized when, despite the base station being within clear sight of Kisii Stadium where the meeting was to be held, an acceptable signal could not be obtained, hence, a functional Internet link could not be established.

Finally, an attempt was made to connect using a CDMA modem provided by Company T. The modem worked quite well and provided a stable service throughout the meeting. The surprise was that the CDMA-based service cost about KSh. 1,000 (USD 13 at that time) in bandwidth costs compared to the cost of equipment rental, installation and bandwidth charges for the WiMax service was KSh. 41,000 for a 1 Mbps link (USD 525 at that time). This is more than 4,000% more expensive yet could not deliver a functioning Internet link let alone provide usable bandwidth. Clearly, the quality of Company K's network was deeply suspect.

Another live streaming event was held at Kisumu in December 2011. This time, due to the bad experiences at Kericho and Kisii, it was decided to test Company T's modem-based services especially because there was a new modem service based on High-Speed Download Packet Access (HSDPA or HSPA) supposedly capable of up to 21Mbps download speeds (see Figure 4). Live tests at Kisumu stadium showed that stable 5Mbps download and 1Mbps upload speeds could be attained.

Figure 4: CDMA-EVDO (left) and HSPA-3G+(right) Modems

The streaming at Kisumu in December 2011 was the smoothest attempt since May 2010. At Mombasa in February 2012, streaming was even smoother and more stable than Kisumu using the high speed 3G+ HSPA modem. There were one or two incidences where software issues forced a restart of the Internet connection but, overall, the HSPA modem provided a virtually uninterrupted link throughout the meeting including a test run on the Thursday before the meeting – four days in all.

One live streaming event was carried out at two locations at Luanda, Angola. The first was indoors at the conference centre of the Hotel Epic Sana Luanda while the second was at an eastern suburb of the city of Luanda. A mobile WiMAX modem had been purchased from one of the Internet service providers in Luanda but tests showed similar issues to what was experienced in Kenya: very low speeds that were not suitable for a live video broadcast. Finally, an HSPA modem was used which, though unable to attain target speeds, provided a stable enough speed for a live video broadcast. With proper tuning of video framerates and size as well as audio sampling rates, it was found that a stable broadcast was attainable at 200 kbps.

Over the ten years that these live streaming events were carried out, the mobile phone providers improved their data services to the point where it was no longer necessary to seek specialized Wireless ISPs to provide a connection. Costs dropped drastically from quotations as high as USD2,000 at the beginning to bandwidth costs of USD10 and equipment costs of barely more than USD50. Internet services changed from specialised firms offering WiMAX and ADSL to mobile telephony offering 3G connections and eventually 4G. Some providers who had market dominance in the early days all but disappeared by 2019. Starting with ADSL, technology moved to WiMAX, then to CDMA EVO, to 3G+ HSPA to LTE.

Starting 2018, firms raced to compete for Internet services. They began to introduce fibre-to-the-home starting with a relatively new entrant, Company J. In one live streaming location where this service was installed in December 2018, it was found to provide unreliable bandwidth possibly because it was a shared service. Other firms have started offering fibre-to-the-home, but the stability of these services was not well established. Upstream issues still exist in provider's networks which negates the advantages of last-mile fibre links. In one case, a simple traceroute isolated misconfigured routers in Company S' network. At that time, it was also found that virtually all network operators provided asymmetric links with the downstream speeds being sometimes several times the upstream speeds. For live streaming, it was the upstream speeds that matter, hence, such links worked against live streaming requirements. New 4G and home fibre services performed well soon after launch but as more clients got on board, the shared links got congested and network performance declined. Company J was particularly affected by this effect. It was also found that 4G network performance was highly dependent on location. Coverage was patchy.

Wireless routers were severely affected by crowds if the router was mounted lower that the general height of the people in the crowd. It was determined that human bodies absorb both Wifi and 3G/4G signals thereby downgrading the Internet link quite severely. To mitigate against this effect, the 4G wireless routers were mounted above the general height of the people in the crowd and connected to the streaming computer with an extra-long Universal Serial Bus (USB) data cable or UTP cable.

In 2020, FTTH matured and offered symmetric links. Because the big open-air meetings as well as church services could not be held during the Covid-19 lockdown, weekly livestreamed services were introduced broadcast from Nairobi. Company S' FTTH was used and worked well until early 2021 when on three days consecutively, the fibre link failed during the hours when the live services were held on Sunday, Wednesday and Friday nights. A second fibre link was sought to serve as backup. It was never established why Company S' FTTH failed on the specific days and times when livestreamed church services were running yet worked fine outside these days and times. Further, Company S has introduced a "fair use" data limit that, when exceeded degrades the link to 1Mbps. This limitation was not received well by clients but was justified because some home fibre customers were reselling their links and consuming unreasonable amounts of data.

In summary, network technologies have rapidly changed over the last ten years from ADSL to WiMAX to HPSA to 4G to home fibre. The key challenges that remain include shortcomings in service coverage and link speed stability. Costs have declined from more than USD500 down to less than USD 10 per day for wireless 4G links. For home fibre, it is about USD 15 per day for a 40 Mbps link. On a number of occasions, VSAT was considered but, aside from high cost and challenging leasing terms, it was found that VSAT providers often had asymmetric up/down links with the download speed much high than the upload which was reverse of live streaming requirements. Internet bonding appliances that allow multiple 4/5G links to operate as one high speed link were also considered but price points were such that their use could not be justified.

4.2. Streaming Software

The second category of challenges to live video streaming was the client-side streaming software. The role of this software was to process the video and audio signal by converting the format into one acceptable to the streaming server (encoding) then uploading the signal in near-real time using the appropriate protocol.

In the early live streaming period, a number of live streaming service providers including Livestream, Justin, Veetle and Ustream were examined before Ustream was selected. One key consideration was the kind of advertising these sites used to support their sites. Ustream permitted the client to select the theme of the advertisements at their site and hence, to some extent, control the kind of advertisements that were displayed to the viewers. The client-side streaming tool recommended by Ustream was their own software called Ustream Producer that run in Microsoft Windows. All tests were carried out with Microsoft Windows due to scarcity of tools that run on alternative operating systems. The outcome of tests with this software were not positive. It was quite unstable and would hang after an hour or so of broadcasting and could not be restarted without re-starting the operating system. It also had serious challenges detecting the Pinnacle MovieBox and would often take more than 20 minutes before Ustream Producer could detect the Pinnacle box. This was unacceptable for real-time broadcast. Ustream Producer was quite sensitive to network bandwidth and would begin to disconnect from the streaming server when network speeds dropped to around 650kbps. There was no acceptable method to tune the software to fit the available bandwidth.

At Mombasa experimentation with the web browser-based Flash tools provided by Ustream was started. However, though more stable than Ustream Producer, the browser's Shockwave Flash plugin crashed repeatedly. Investigations revealed that this issue seemed to be browser-independent and was probably due to a bug in the Flash Player provided by Adobe, the company that manufactures this software. During the Nyeri meeting, an opportunity was provided to stream using the fee-based Kingdom Stream provider based in Ireland. Kingdom Stream used the Adobe Flash Media Live Encoder (FMLE). The tests at Nyeri, aside from network instability, were quite successful. It was discovered through online research that FMLE could broadcast to Ustream, hence thereafter, FMLE was used in the broadcasts and proved to be vastly superior to Ustream Producer. Its bandwidth requirements were much lower and highly customisable. It was possible to get a good video broadcast acceptable to the viewers at only 200kbps a speed that would be virtually impossible to operate if using the Producer.

The key disadvantage FMLE had was the inability to access Ustream recording feature so that one could not record video on Ustream while streaming with FMLE. However, this online recording facility was not very friendly because the recording often stopped on its own accord after about two hours and accessing recorded videos was not easy. Therefore, a decision had been made after the Kakamega meeting of December 2010 to record the video locally and upload the recorded video to YouTube as 15-minute clips. After a few months YouTube permitted longer videos, so the 15-minute limit was eliminated making YouTube quite convenient as an online repository for the video content produced in these meetings. The initial YouTube channel used was called "repentancechannel" and is still active though much of the original content has been replaced.

It was discovered that FMLE has tools to customise inputs from video capture cards especially the provision for selecting the video format received from the camera (National Television Standards Committee (NTSC), Phase Alternating Line (PAL) or Séquentiel Couleur à Mémoire (SECAM)). The absence of this feature was the key weakness of the Ustream Producer. FMLE also provided numerous features to modify the broadcast signal parameters therefore was very flexible. Though discontinued, FMLE features serve as a reference standard for judging streaming software. These features include:

- FMLE allowed codecs and protocols to be selected.
- FMLE could survive network disconnections lasting several minutes because it had a ping-based "keepalive" mechanism.
- FMLE monitored and reported dropped packets on the ingress and egress.
- FMLE was highly customisable allowing frame rates, video sizes, and audio parameters to be modified to suit the network conditions.
- FMLE was free both in the sense that it is freely downloadable and requires no fees or registration but also did not insert advertisements in the video stream or place a logo in the broadcast video frames.

However, FMLE seemed to be affected by web browsers. When FMLE was running together with a Web browser, a deadlock seemed to occur that required the operating system to be restarted and, consequently, the loss of several minutes of live broadcast.

Though the Adobe FMLE was very successful as the streaming software on the client end, there are more advanced features that it lacked. Key among these is the ability to handle and even mix more than one video source. In TV studios, this function is handled by a video mixer. Some entry-level software-based broadcast management tools provide these features. Notably, a tool called VidBlaster was tested. Though it was a commercial tool with prices starting at about USD200, a free limited version was available which had limitations and would also insert a logo in the upper right-hand corner of each broadcast video frame.

Since these tests in early 2011, VidBlaster has grown and developed becoming VidBlasterX. There were two other limitations of VidBlaster aside from the price. One was that its resource requirements were high. On the dual-core computer used for these tests, it would consume 100% of the CPU resources and most of the RAM. The other challenge was that it was not able at that time to broadcast directly to the Ustream servers. Instead, it would be set up to generate a stream to a virtual device from which Adobe FMLE was able to pick up. Vidblaster had more limited stream monitoring tools than FMLE. Indeed, it had no stream monitoring interface whatsoever neither was it as flexible in providing the means to configure the stream parameters such as framerate, sampling rates and frame size. However, if one had a single video signal, the value added by ViBlaster was limited to the ability to add graphic and text overlays to the video signal. This means that one could add subtitles and logos to their broadcast in real time. For a more sophisticated set up with multiple input video signals and the need for overlays, picture-in-picture or other needs, this tool looked promising except that a more powerful computer was clearly required.

After IBM bought Ustream, it became clear that the free live streaming on Ustream was going to come to an end. In 2017, it was decided to switch to YouTube Live as the streaming platform. At the same time, FMLE started to show signs of ageing. Adobe was no longer updating the software, hence, Open Broadcast Software (OBS) which offered a lot of professional features was adopted.

4.3. Video and Audio Capture

Digitizing video is not a trivial task. The kind of camera initially used in this case study produced standard definition (SD) PAL video (aspect ratio of 4:3). The last two tests were done with HD format video (9:16 aspect ratio). The streaming servers used require H.264 encoding for video. In the Ustream support page at that time, H.264 was recommended as the ingress codec to the streaming server. The PC must, therefore, encode the PAL video into H.264 before streaming it up to Ustream servers. In later events, audio was encoded used Advanced Audio Coding Low-Complexity (AAC-LC). The audio stream consumed very little bandwidth. With a mono 22,050Hz sampling rate, the audio bitrate would be 48kbps with compression.

The key challenge with video capture was getting the video capture hardware to be recognized by the streaming software. There was also a huge latency problem. In the first two trials with live streaming, it was also found that the streaming video fell far behind the real events by as much as one hour. The main cause was thought to be the speed of video processing and the Internet speed. In the more recent tests at a higher Internet speed (1.5 Mbps or better), it was found that the delay (latency) between the real event and the streamed video was no more than a few seconds but fluctuates up and down. The better the Internet connection, the shorter the time lag or latency.

In theory, the processing load can be reduced by carrying out video conversion from composite PAL (or NTC and SECAM) to H.264 on the video capture hardware. The initial type of video capture hardware used in this research did not have such capacity, hence, the broadcast computers needed to do the processing. The computing resource requirements are related to the type of streaming software used. It was found that VidBlaster was the most resource-intensive streaming software used compared with Ustream Producer and Adobe FMLE. The latter required the least computing resources.

H.264 video codec was found to be lighter in terms of bandwidth consumption than the VP6 codec. Only these two formats were available in FMLE. H.264 was relatively new at the start of the live streaming events and was not preferred by Ustream at the time these streaming events begun as indicated in their support forum at that time. Therefore, in seeking to

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optimize the live streaming experience, the ingress (input) codec is an important variable to consider. The ability of the streaming tools to provide the more recent, high-efficiency formats such as H.264 (eventually H.265) can contribute quite significantly to improving the viewer experience and minimizing bandwidth consumption and hence the costs and stability of the broadcast.

In 2016, an encoding box from Videon was tested. The box, running Linux, was able to stream directly to Ustream or YouTube Live. It eliminated the need to use a computer and encoding software. The Videon box requires higher bandwidth than FMLE and was introduced at the same time as 4G services came on stream in Kenya's major towns and cities. The major challenge with the Videon box was overheating and damage from earthing loops. An earthing loop mishap destroyed the box requiring a replacement. Overheating was a challenge with the early model of the Videon box. Latter redesign eliminated the heating issue substantially but not entirely. However, the box cost close to USD1,000 which adds to the cost of live streaming. The box can handle only one video stream, hence, to stream multiple cameras, a video mixer is required. Further, the box has limited stream tuning features that would allow a wide range of framerates, Internet bit rates, audio sampling rates, codecs, protocols and other stream parameters to be customized.

When using the Videon encoding box, video processing on the computer was eliminated hence, the PC's resource constraints became irrelevant. However, in December 2017, tests were done using 4G phones to YouTube Live that now allows up to 7 camera inputs. The phones used were relatively lower-end 4G phones with 3GB of RAM, MediaTek MT6737 quad-core chipset clocking a maximum of 1.25GHz and an ARM Mali T720 MP2 GPU. The major issues were network instability (a shared 4G link) and phone battery consumption. With multiple video inputs, it was found essential to create a video production structure with a director, camera operators and camera assistants. The phone provides complete mobility since they are 100% wireless within the WIFI signal radius but need multiple power banks to provide power for extended periods of time. The software used on the phones was the Larix Broadcaster which has a lot of flexibility regarding settings for the transmission. However, YouTube Live has a limited set of permissible video resolution settings that reduces this flexibility since the source must match the ingress requirements. HD streaming at 720p was achieved with two phone cameras running for close to 11 hours continuously [28].

Due to the lack of flexibility of encoding boxes such as the Videon box, and the switch to Serial Digital Interface (SDI) video rather than composite video, it was decided in 2018 to try SDI/HDMI (High-Definition Multimedia Interface) video capture cards to encode video. These are inexpensive as compared to the encoder boxes and offer the advantage that they connect to a computer's USB port hence provide the opportunity to use streaming software to provide graphics and text overlays.

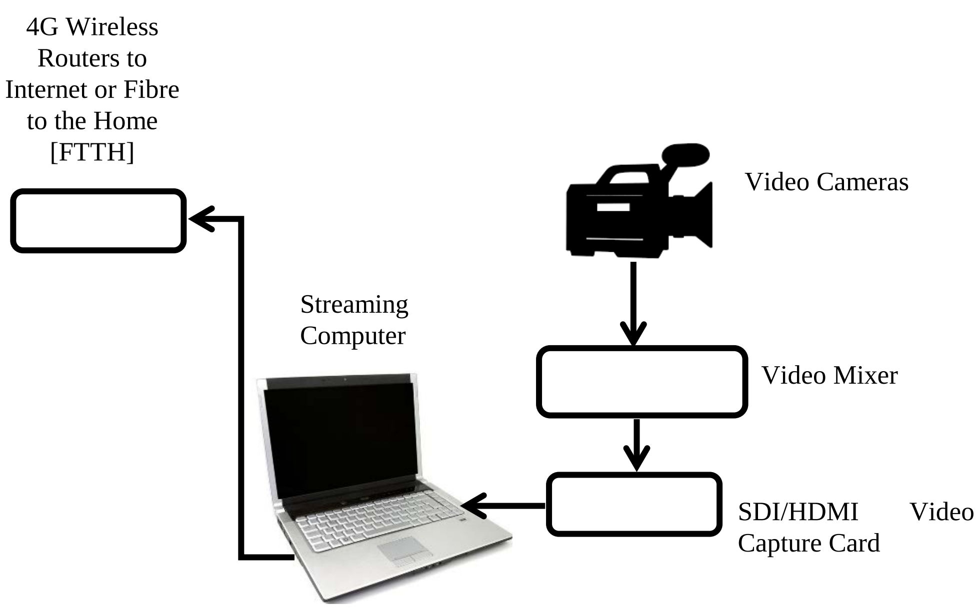

Figure 5: Simplified final streaming set up

Note. The mixer allows multiple video inputs to be provided and selected. The use of link aggregation software (Speedify) allows the automatic selection of the best route to the Internet.

4.4. Video Management

YouTube offers a recording feature that allow the whole live-streamed video to be stored on YouTube for later viewing. There are cases when a portion of stored video needed to be removed for various reasons. As an example, a live camera may stop displaying video when its storage media filled up. In the early days of using YouTube live streaming, there was no simple way to edit recorded live streams. Later, YouTube improved its online video editor to ease the process of editing recorded video.

YouTube live streaming does not provide features to add overlays and graphics such as logos to the video while streaming. One way to get around this is to use software such as OBS to add the graphics and overlays. Video mixers provide these features but cost at least USD1,000 for a basic mixer. These video mixers greatly improved live video streaming during conferences because the speaker could use video clips to support their presentation. However, absence of video clip management system caused many unpleasant disruptions of live video streams as the speaker waited during a live transmission for the right clip to be found.

4.5. Operating System Issues

Over the period these live streaming events were carried out, it was discovered that various elements in the hardware and software chain, i.e., workflow, can influence the outcome quite a lot.

1. It was found that encoding software such as FMLE was negatively affected by web browsers often resulting in dreadlocks that required the operating system to be restarted. Ensuring browsers were closed and monitoring the stream from a separate computer from the streaming PC helped to stabilise the system. Ideally, all non-essential software services should be terminated on the streaming computer to reduce resource consumption by these non-essential services.
2. It was suspected that poor or buggy USB drivers for video capture cards was the reason the encoding software, especially Ustream Broadcaster, took a long time to detect video capture cards. Testing USB drivers was beyond the scope of this case study.
3. CPU and memory loading can have negative impact on the streaming quality, hence, when streaming from a PC or phone/tablet, CPU power and amount of RAM is a major variable to consider.

4.6. Electrical Supply Issues

Earth loop currents caused severe equipment damage in August 2016 and caused interconnection issues in previous meetings before the problem was identified and properly diagnosed. In two meeting, during an indoor conference, the earth loop issues badly affected the video signals displayed on conference screens.

The initial solution applied was to ensure all interconnected equipment was drawing power from the same phase in a 3-phase electricity supply system. However, this approach is not optimal since it prevents electric power balancing across all three phases considering that the public address, from where the audio signal was obtained, is a major load on the electric supply. This approach was only partially successful. The solution that worked was to electrically isolate the indoor audio/video network from the video/audio sources by inserting a wireless Audio Visual (AV) Sender or other devices that can achieve electrical isolation. Though HDMI AV Senders became available towards the end of this case study, composite video devices were used because the internal video network was composite video (480p). Distributing HDMI video to 25 TV monitors was technically challenging and was not attempted.

4.7. Video Production

In a few instances, multiple camera and video clip sources were used as inputs to the live stream with a video mixer used to select the inputs. To coordinate all the people involved, it was found necessary to have a production director and a communication tool to direct all the persons involved in the production. The situation is similar live video production in a news studio. Camera operators required assistants to take care of such issues as moving cables or providing power banks in the case where mobile phones were used as cameras. YouTube provides a rudimentary online mixer that allows up to seven cameras to be managed but is not comparable to a hardware-based video mixer.

4.8. Other Factors

There were few other issues that seriously affected the live stream. For the sake of completeness, and for those readers who may have had little experience with open air environments, signal cables can be a source of much grief especially where cable faults are intermittent and difficult to troubleshoot. It is best to test cables in advance with real audio and video signal injection while monitoring the other end with suitable equipment such as a small TV (video) or headphones (audio). Indeed, it was best to test all equipment in advance since there is often no technical support available in the kinds of locations the live streamed events were held.

In one instance, while trying to troubleshoot a video cable fault, the team members were forced to travel about 30km in the middle of the night to look for a video splitter. Though the splitter was found, it turned out not to have been the cause of the problem. This kind of trouble was particularly true of audio cables. In one instance at Kisumu, after several hours experiencing spurious noise on the audio link, it was discovered that the source of trouble was a poorly terminated coaxial audio cable. A simple continuity test cannot detect such faults. Visual inspection may provide much better evidence of such faults.

About electrical power, the key challenges were power outages and voltage fluctuations. Both challenges needed to be addressed. In one instance a standby generator's voltage suddenly rose and resulted in blown capacitors in one of the power amplifiers that formed part of the public-address system. A good quality standby generator became mandatory. A UPS was used to act both as a very short-term power provider and as a voltage regulator to filter out voltage surges and spikes.

5. Summary and Conclusions

Though live video streaming had been steadily picking up pace before the Covid-19 pandemic, massive increase in live streaming occurred in the early part of the pandemic. Applications such as Zoom, Google Meet, Microsoft Teams and Cisco Systems WebEx picked up a lot of traffic during this period. In this study that tracks the change in live video streaming environment in Kenya over a ten-year period from May 2010 to April 2021, a transformation has been documented. In the early days, it was a big struggle to find a stable Internet link capable of carrying a live video streamed link. Technologies such as ADSL and WiMAX were considered and tried without good outcomes. Mobile Internet was still at 2G stage with GPRS and EDGE. However, as time progressed, 3G broadband based on CDMA EV-DO was introduced then HSPA. Modems based on these 3G formats greatly improved the live streaming experience both from the broadcast end and the receiver end. Later, 4G LTE came along and allowed stable HD live streaming up to 1040p resolution to be streamed for up to 11 hours continuously. Table 1 shows a summary of this transformation.

Table 1: Summary of Changes to Streaming Quality 2010 - 2021

Phase	**Period (Dates)**	**Camera Type**	**Video Capture**	**Encoding**	**Internet Connection**	**Video Resolution**
1	2010-2012	Fixed	Pinnacle Movie Box 710/510	Ustream Broadcaster	WiMAX	Low 240x180
2	2012-2015	Fixed	Pinnacle Movie Box 710/510	FMLE	CDMA EVO/3G	320x180
3	2016-2017	Fixed with Vision Mixer	Videon Encoder	Videon Encoder	4G	720p
4	Dec. 2017	Smartphone	4G Smartphones	Larix Broadcaster	4G	720p/1040p
5	Mar/Apr 2018	Fixed with Vision Mixer	Videon Encoder	Videon Encoder	FibreHome @ 25Mbps shared	720p/1040p

Phase	Period (Dates)	Camera Type	Video Capture	Encoding	Internet Connection	Video Resolution
6	Dec 2018 – Aug 2019	Fixed with Vision Mixer	SDI/HDMI Capture card	OBS	LTE 4G with Speedify link aggregator	720p/1040p
7	March 2020 – present (April 2021)	Fixed with Vision Mixer in a residential environment	SDI Capture card	OBS	Fibre to the Home with Speedify link aggregation	720p/1040p

It was the advent of 4G Internet and FTTH that caused the greatest change in the live streaming performance. It was found that crowds could disrupt both Wi-Fi and 4G signals necessitating wireless network devices be raised above the heads of the crowd to reduce signal attenuation. In a number of occasions, VSAT was considered but, aside from high cost and challenging leasing terms, it was found that VSAT providers often had asymmetric up/down links with the download speed much high than the upload which was reverse of live streaming requirements. Internet bonding appliances that allow multiple 4/5G links to operate as one high speed link were also considered but price points were such that their use could not be justified.

The change in cabling from low quality RCA coaxial to high quality factory-made SDI reduced signal quality issues arising from low quality cables and connectors. Live streaming tools improved greatly over the years. The initial tools from Ustream became obsolete and Ustream was absorbed into the IBM corporate structure. Adobe abandoned FMLE while at the same time, the Pinnacle box was replaced with encoder boxes such as the Videon box. The free and open source OBS has now become the standard streaming software capable of delivering professional results for limited-budget operators. Video mixers costs dropped considerably over the years with prices falling from several thousand USD to around USD1,000 for a basic vision mixer. These mixers allowed live streams to be enhanced with illustrative video clips though the absence of effective video clip management systems degraded the live stream through delays in locating the clips. Electrical power issues continued in certain in-door locations most likely due to electrical wiring faults within these premises. The resulting earth loops can be quite destructive of streaming equipment.

In a number of instances while using FTTH but especially while using WiMAX, there were cases of suspected sabotage of live video streams by employees or technical support staff in the network provider companies. However, these suspected cases were not pursued due to the difficulty of collecting objective supporting evidence to support such allegations. However, conversely, there were cases where a network provider, at their cost, set up a Base Station in the field of the meeting and tuned their Internet provision to optimise the video streaming link performance.

6. Recommendations

The following are recommendations deriving from experiences gained in this case study.

6.1. Internet Links

A stable Internet connection is essential for successful live streaming. Bandwidth requirements vary depending on the video and audio quality. IBM offers suggestions for bandwidth and other requirements [29]. Link aggregation or multiplexing tools such as Speedify are very useful in places with fluctuating 4G signals. The tool allows the streaming computer to maintain up to three links (Ethernet, USB and Wifi) and choose the best in real time for optimal connectivity. While Internet bonding solutions became available over the course of the ten years, their costs remained prohibitive for the church organization that was live streaming in this case study.

6.2. Cabling

Poor cabling, including electrical supply, can be a cause for serious faults and equipment damage. Systematic installation with clear wiring diagrams followed by testing with real signals (video/audio) is important.

6.3. Video Capture Hardware

The best video capture hardware is one that fits the video input format and physical interfaces and does hardware-based encoding, therefore, reduces resource consumption on the streaming computer. The most common physical interfaces for HD video are SDI or HDMI. Additionally, it should not overheat even after several hours of use nor should it be extra-sensitive to electrical power supply fluctuations. Pass-through ports are especially useful. It means the device should ideally have output ports that match the inputs. If it has SDI and HDMI inputs, there should be SDI and HDMI outputs allowing input signals to be shared with other consumers such as an array of LCD panels in a conference centre.

6.4. Streaming Software

Streaming software should be stable with no memory leaks or dreadlocks even after several hours of continuous streaming. For this kind of application, such software should ideally have low CPU/RAM usage; be low cost; and have professional features such as overlays, graphics, framerate tweaks and frame size, audio sampling rates. A recording feature is particularly useful. Open Broadcaster Software (OBS) met most of these requirements.

6.5. Computing Power

The higher the framerate and resolution, the more CPU and RAM will be required to process the video. It is advisable to stop all unrequired services on the streaming computer. Tools such as Microsoft **Sysinternals** can assist to identify and stop/kill non-essential services on the streaming computer.

6.3. Physical Environment

Create a conducive physical environment including cooling hardware where necessary, protecting from moisture and from direct sunlight. Install and organise cables carefully to prevent damage, short circuiting, and earth loops. Take care of physical security – devices are easily lost or stolen in crowded conferences or open-air meeting venues. Ensure equipment operators have enough experience working with the hardware and software tools. Monitor the video and audio signals that are being streamed.

7. Applications

After the Covid-19 lockdowns begun, there was little need to persuade people about the need for video streaming. The applications of live video streaming that have now become mainstream include:

- Video conferences and meetings
- Religious services
- School and college lessons
- Product demonstrations
- Healthcare consultations
- Family and social events – weddings, funerals, birthdays, get-togethers

The full potential of live video streaming has not yet been realised especially for developing country environments. Of particular interest is the ability to provide training to farmers and small enterprise operators without the need to travel long distance to access such training. Valuable virtual extension services in agriculture, small enterprises and healthcare can be built around video streaming.

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9. References

[1] Cisco and affiliates. Cisco Visual Networking Index: Forecast and Trends, 2017–2022, 2019 White Paper. [Online] Available from: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html [Accessed 30 August 2019].

[2] Nokia: Nokia Deepfield Network Intelligence Report: Networks in 2020, 2020. [Online] Available from: https://onestore.nokia.com/asset/210130 [Accessed 15 April 2021].

[3] Ruether, T. Live streaming and COVID-19: When Novelty Becomes Necessity, 2021a, March 23. [Online] Available from: https://www.wowza.com/blog/live-streaming-and-covid-19-when-novelty-becomes-necessity [Accessed 28 March 2021].

[4] Plitnichenko, L. 10 Challenges of E-learning during Covid-19, 2020, April9. [Online] Available from: https://medium.com/jellyfish-techco/10-challenges-of-e-learning-during-covid-19-5f5060981e24 [Accessed 16 April 2021].

[5] 5. FACT sheet: The American jobs plan 2021, April 08. [Online] Available from: https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/ [Accessed 15 April 2021].

[6] Fuller, M. Y., Mukhopadhyay, S., & Gardner, J. M. Using the periscope live video-streaming application for global pathology education: A brief introduction. Archives of Pathology & Laboratory Medicine, 140(11), 1273-1280, 2016. doi:10.5858/arpa.2016-0268-sa

[7] Repent & prepare the way, 2021. [Online] Available from: https://www.youtube.com/c/RepentPreparetheway/about [Accessed 15 April 2021].

[8] Wu, M., & Gao, Q. Using live video streaming in online tutoring: Exploring factors affecting social interaction. International Journal of Human–Computer Interaction, 36(10), 964-977, 2019. doi:10.1080/10447318.2019.1706288

[9] Sekret, I., Durmus, S., Gurer, M. D., & Curaoglu, O. From face-to-face teaching to online tutoring: Challenges, solutions and perspectives. Universities in the Networked Society, 171-183, 2019. doi:10.1007/978-3-030-05026-9_10

[10] Breslauer, D. N., Maamari, R. N., Switz, N. A., Lam, W. A., & Fletcher, D. A. Mobile phone based clinical MICROSCOPY for global health applications. PLoS ONE, 4(7), 2007. doi:10.1371/journal.pone.0006320.

[11] Contreras-Naranjo, J. C., Wei, Q. & Ozcan, A. Mobile Phone-Based Microscopy, Sensing, and Diagnostics. IEEE Journal of Selected Topics in Quantum Electronics, 22(3), 1-14. doi:10.1109/JSTQE.2015.2478657, 2016.

[12] Ruether, T. Low-latency claims and how to decipher them: Wowza, 2021c, March 23. [Online] Available from: https://www.wowza.com/blog/low-latency-claims-and-how-to-decipher-them [Accessed 15 April 2021].

[13] Wowza Media Systems. Video Streaming Latency Report, 2019, September 16. [Online] Available from: https://www.wowza.com/wp-content/uploads/Streaming-Video-Latency-Report-Interactive-2020.pdf [Accessed 16 April 2021].

[14] Cusiac, G. M. Why SRT, HLS, and MPEG-DASH are the future of stream-ing, 2020, June 30. . [Online] Available from: https://www.epiphan.com/blog/why-srt-hls-mpegdash-streaming/ [Accessed 15 April 2021].

[15] Modern Video Streaming in the Enterprise: Protocols, caching, and WAN optimization. [Online] Available from: https://panopto.docsend.com/view/wcrj3hi [Accessed 15 April 2021].

[16] Ruether, T. MPEG-DASH: Dynamic adaptive streaming over http explained, 2021d, March 30. [Online] Available from: https://www.wowza.com/blog/mpeg-dash-dynamic-adaptive-streaming-over-http [Accessed 15 April 2021].

[17] Ruether, T. RTMP streaming: The real time messaging protocol explained, 2021e, March 23. [Online] Available from: https://www.wowza.com/blog/rtmp-streaming-real-time-messaging-protocol [Accessed 15 April 2021].

[18] DASH-IF Live Media Ingest Protocol, 2021, February 26. [Online] Available from: https://dashif-documents.azurewebsites.net/Ingest/master/DASH-IF-Ingest.html [Accessed 16 April 2021].

[19] YouTube live STREAMING Ingestion Protocol Comparison, 2020, December 8. [Online] Available from: https://developers.google.com/youtube/v3/live/guides/ingestion-protocol-comparison [Accessed 16 April 2021].

[20] Peck, R., Cenzano, J., Li, X. & Reznik, Y. Towards Mass Deployment of CMAF. NAB Broadcast Engineering and Information Technology Conference, April 2019, Las Vegas, NV, 2019. [Online] Available from: https://www.researchgate.net/publication/333040216_Towards_Mass_Deployment_of_CMAF [Accessed 16 April 2021].

[21] ISO/IEC 23000-19:2018, 2020, March 19. [Online] Available from: https://www.iso.org/standard/71975.html [Accessed 16 April 2021].

[22] Ahmad, N., Ahmad, N., & Salvadori, K. Building 2Africa, a Transformative subsea cable to better Connect Africa, 2020, May 13. [Online] Available from: https://engineering.fb.com/2020/05/13/connectivity/2africa/ [Accessed 16 April 2021].

[23] Cheng, Y. 2Africa: A Transformative subsea cable for future internet connectivity in AFRICA announced by global and African Partners, 2020, May 14. [Online] Available from: https://www.businesswire.com/news/home/20200514005389/en/2Africa-A-Transformative-Subsea-Cable-for-Future-Internet-Connectivity-in-Africa-Announced-by-Global-and-African-Partners [Accessed 16 April 2021].

[24] Otieno, D. Safaricom 5G is here, and This is what you need to know!, 2021, March 26. . [Online] Available from: https://tech-ish.com/2021/03/26/safaricom-5g-kenya-launch/ [Accessed 28 March 2021].

[25] The National Council for Law Reporting (2019). Civil Suit 179’A’ of 2018, 2019. . [Online] Available from: http://kenyalaw.org/caselaw/cases/view/180965 [Accessed 16 April 2021].

[26] United States Copyright Office. Section 512 of Title 17: A Report of the Register of Copyrights, 2020. [Online] Available from: https://www.copyright.gov/policy/section512/section-512-full-report.pdf [Accessed 16 April 2021].

[27] Auma, W. O. Copyright in the Digital Age: An Assessment of Kenya’s Legal and Institutional Framework for the Protection and Enforcement of Copyright [Masters dissertation, University of Nairobi, Kenya], 2017.

[28] Githeko, J. M. Bishop Prof. Jason Githeko YouTube Channel, 2019. [Online] Available from: https://www.youtube.com/user/RepentanceRevival1 [Accessed 28 August 2019].

[29] IBM. Internet connection and recommended encoding settings. [Online] Available from: https://support.video.ibm.com/hc/en-us/articles/207852117-Internet-connection-and-recommended-encoding-settings [Accessed 18 April 2021].

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