Location-Based Social Video Sharing over Next Generation Cellular Networks

Abhishek Roy, Pradipta De, and Navrati Saxena

ABSTRACT

The popularity of video sharing over social networks is straining service providers to maintain high quality of service. With the introduction of live video streaming over social networks, video sharing is truly becoming social and real time. However, existing video distribution architecture, split across content providers and mobile network operators, cannot leverage cross-provider information. We argue that MNOs can explore the knowledge of users' location to route video traffic intelligently. This can enable better quality of experience for live social video sharing. We show different scenarios in existing cellular networks, where user experience can suffer due to current video distribution mechanism. We propose that use of the location information of the receiver with respect to the sender can be exploited by next generation cellular networks for improving video streaming quality. Our simulation experiments validate that on all QoE metrics there is opportunity for significant improvement in live video streaming by using relative locations of the receivers and senders.

INTRODUCTION

Video streaming has long been touted as one of the killer applications for mobile devices. But limitations of technology, whether due to limited resources on mobile devices or inadequate infrastructure support, have hindered the rise of video streaming in social media space. As the network capacity has evolved, and mobile devices have become more powerful, the scenario is changing fast. We are witnessing the rise of several companies, such as Vine and Instagram, which have popularized short video sharing, and Meerkat, Twitter's Periscope, and Twitch.tv, which are focused on live streaming of user generated video content. In 2011, Erman *et al.* reported that 40 percent of cellular traffic is composed of video streaming [1]. In the Internet, video streaming constitutes 66 percent of the total traffic, according to Cisco Visual Networking Index: Forecast and Methodology, 2013–2018, 2014.[1] Social video streaming is certain to fuel the growth of video traffic further.

Social video sharing is a natural progression of text- and image-based social networks. Strover and Moner studied the generational shift in viewing media. They concluded that young people, especially those in colleges with high-speed Internet connectivity, are contributing toward sharing and creating new content [2]. They form the new generation of "ProdUsers," where the roles of consumers and users of content are intertwined, thereby leading to the new hybrid role [3]. The ProdUsers' desire to share content is met by the market with novel applications, the latest among them being live video sharing over social networks. This mode of live video sharing truly embodies social sharing as it connects groups in real time. We consider live streaming of user generated video to social groups as "social video sharing."

The traditional Internet architecture follows a layered design, where dedicated service providers cater specific services, like content management, content distribution, and infrastructure support. As shown in Fig. 1, there are three key entities in the content distribution: content providers, content distribution networks (CDNs), and mobile network operators (MNO). Often these providers work in isolation with limited cross-provider information sharing. A user-generated video content must travel upstream to the content provider, and then flow downstream to the consumers. At each layer, the aim of the provider is to adapt independently to deliver better quality of experience (QoE) to the user. However, lack of cooperation across providers leads to complex and sub-optimal adaptation techniques, as shown by [4].

The benefits of information sharing across providers is not unknown. Jiang *et al.* observed that Internet service providers are taking on the lucrative role of content providers. Merging of the roles can lead to better coordination in traffic engineering, which can be especially beneficial for high-volume latency-sensitive video traffic [5]. Google and Amazon are more recent examples of providers, which are taking on multiple roles to enhance their service quality. There have also been alliances across CDNs and MNOs to improve service delivery [6]. It is not farfetched to assume that network architectures will

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[1] http://tinyurl.com/mev32z8

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evolve to allow more information sharing across providers [7]. With this shift in network design toward greater collaboration across providers, it is expected that in the future, video distribution architecture will also evolve and share information across providers to deliver higher QoE to the users. This is our assumption for the next generation cellular network (NGCN).

This article explores avenues for enhancements in video distribution over cellular networks from the perspective of the MNOs. We specifically focus on live video streaming, where MNOs can leverage the users' location information within cells to improve QoE. In the next section we explore the challenges in current video distribution. Next, we present multiple scenarios that we believe open up opportunities to enhance quality of social video sharing over fourth generation (4G) Long Term Evolution (LTE) networks. We show the benefits of bypassing the content providers in the video distribution path, especially when content providers and MNOs can share information about the senders and receivers of the live video stream. Our observations are validated using simulation experiments.

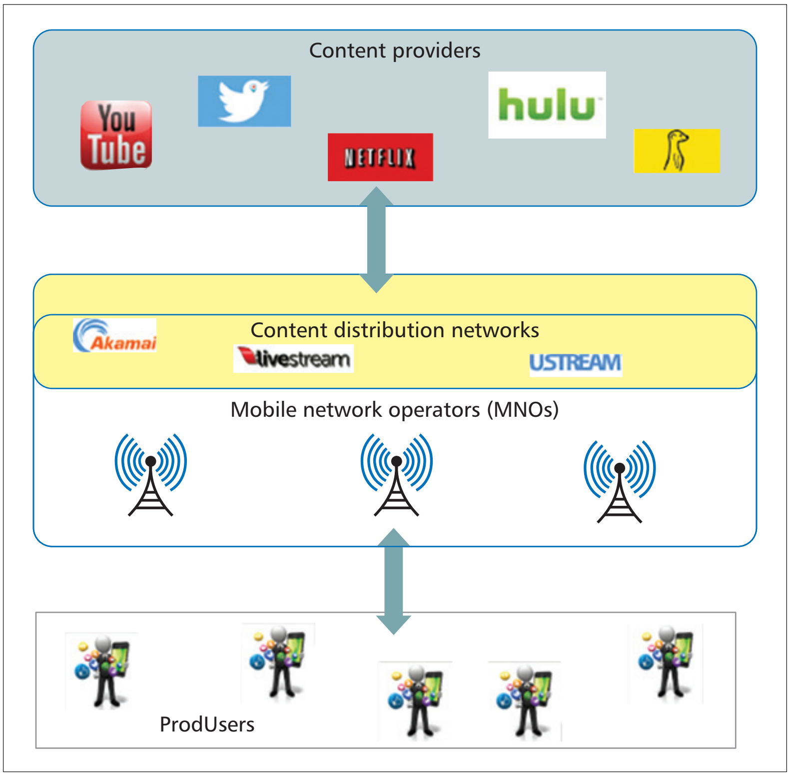

Figure 1. Different players in a typical video content distribution process.

CHALLENGES IN SOCIAL VIDEO SHARING OVER EXISTING CELLULAR NETWORKS

Figure 2 shows the video distribution process over 4G LTE cellular networks. The evolved NodeB (eNB) in 4G cellular networks is the evolution of the base station (or Node B of 3G) for all radio network functions, like scheduling, radio resource management, and security. Unlike 2G/3G networks, 4G eNBs do not have any separate controller and are interconnected with each other by X2 interfaces. eNBs are also connected with the System Architecture Evolution (SAE) gateway in the Evolved Packet Core (EPC) via the S1 interface. EPC is the all-IP evolution of the general packet radio service (GPRS) core network. It is responsible for all 4G core network operations, like connection (session) establishment, overall control, mobility management, quality of service (QoS), and policy enforcement. The SAE gateway is the terminal node of 4G cellular networks for packet transmission to and from external networks. Traditional video servers connect to the SAE gateway to deliver content to the users.

In existing 4G LTE systems, video traffic is routed to the video content server via LTE eNB and EPC networks. While LTE cell capacity is a few hundred users, a single EPC and a video server typically serve hundreds of eNBs, servicing thousands of users. Thus, even with Gigabit Ethernet link capacity, the network links between the video server and the core network, as well as the downstream links to the users, may saturate quickly. With high data traffic required for streaming, this can degrade streaming quality, especially when multiple users are streaming simultaneously.

The increasing popularity of mobile video sharing through social networking websites and mobile-originated, peer-to-peer video sharing are threatening to make the problem even worse. Unfortunately, legacy cellular 4G networks do not exploit the location of social video users while routing the packets. Video traffic is sent upstream to the content servers, and then sent downstream from the video servers to the receivers. Streaming to the content provider is necessary if the video needs to be stored, but for faster delivery to users, it can be enhanced by generating another stream which can follow a different network path that leverages receiver location with respect to the sender. We consider the scenario where the video content creator is streaming live to a receiver. Depending on the relative location of the receivers, the MNO can use the location information to route the video more intelligently than the content provider.

With the impending wireless evolution toward 5G, there is also a shift toward more device-centric architecture from traditional network-centric architecture design [8]. Evolved multimedia broadcast and multicast services (eMBMS) [9], multicast broadcast single frequency network (MBSFN) [9], and emerging device-to device (D2D) communications [10] can also be explored for better utilization of cellular network resources. While eMBMS and MBSFN are currently tailor-made for server-based video applications, D2D communications are expected to have native support in 5G wireless by exploiting the advantage of proximity-based direct mobile-to-mobile communications. NGCNs are expected to explore these emerging communication technologies to develop the more efficient social video sharing architecture needed to improve the video QoE.

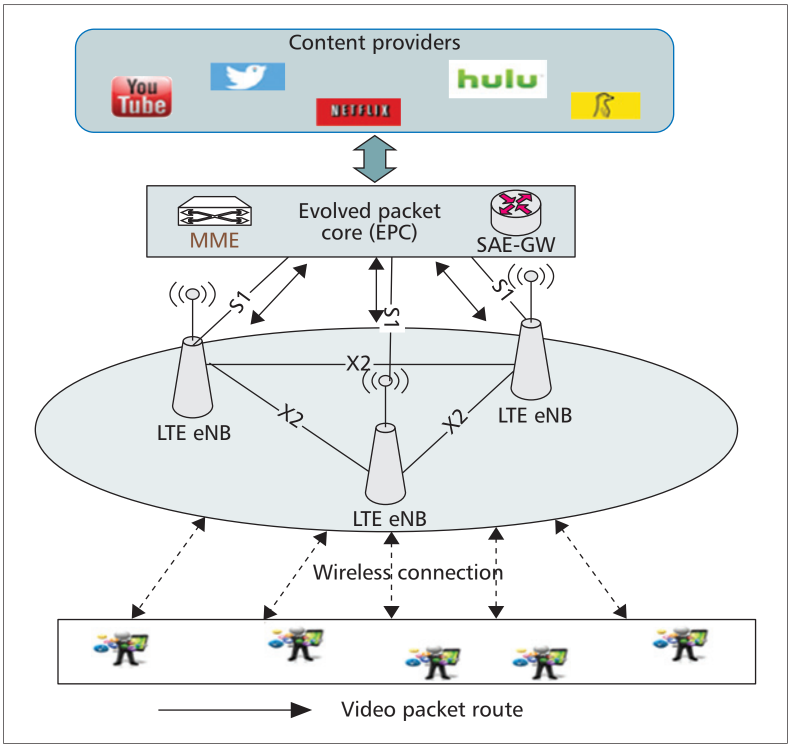

Figure 2. LTE network architecture showing the organization of the network infrastructure elements, like eNB and EPC, and the connection to the servers hosted by the content providers.

LOCATION-BASED SOCIAL VIDEO SHARING

We present an alternative delivery mechanism for live social video streams that can be supported by MNOs using additional information about users that are subscribed to the MNOs. Depending on the location of the social video receivers, an NGCN can reroute social video streams directly from the nearest network node that is shared by the video sender and receivers. This will help the video traffic bypass the network elements and links, thereby significantly reducing network load, delay, and jitter, and improving the video QoE, as well as cell capacity.

In the proposed video distribution scenarios, as shown in Fig. 3, content providers must share the user identity with the MNO. There is an initial signaling phase, when the MNO must map the user identity to the user's location within the network. Once the mapping is established, the streams can be rerouted using the mapping without reaching the content provider. In this model, the streams are not stored by the content provider for streaming on demand. Meerkat currently uses a similar model, where receivers can only join a live stream but cannot use playback. At present, in LTE networks, during the session establishment phase, gateways use IP and transport layer information, like service type, source and destination address, and port numbers, to map every session to a unique Enhanced Packet System (EPS) bearer with a specific QoS class identifier (QCI) [11]. The bearer information is conveyed from the gateways to the corresponding eNBs and UEs by exchanging radio resource control (RRC) connection setup messages. Once the RRC connection and dedicated bearer are established, every UE (in the uplink) and eNB (in the downlink) map the dedicated EPS bearer into a unique logical channel. This logical channel identification (LCID) is contained in the LTE medium access control (MAC) header. The eNB can uniquely identify a video connection and its QCI using this LCID. Once the identity of the sender and receivers are shared by the content provider, the LCID can be mapped to the identities. Subsequently, a video stream can be rerouted by the eNB without reaching the content provider. This introduces additional IP lookup overhead at the eNBs. However, LTE eNBs, equipped with high-performance processors such as Octeon 8-core processors, are capable of processing high traffic rates with negligible additional latency for IP lookup.

Next we use four different scenarios to illustrate how video receivers' location can be exploited by the MNO for more efficient social video sharing.

- As shown in Fig. 3a, if the social video source and the intended receivers are in the same cell, the video packets from the video source will traverse the uplink to the LTE eNB. The eNB, in turn, will directly transmit the video packets over the downlink to the video receivers. Thus, the system can shorten the route of the packets between the sender and the receiver by eliminating the path from the eNB to the video server (seNB → core network → video server → core network → teNB). This results in significant improvement in delay and jitter of video streams.
- Recently, D2D communication [8, 10] among users in close proximity is emerging as a communication mechanism in 5G standards. As shown in Fig. 3b, social video sharing is expected to efficiently explore this proximity-based D2D communication to improve video delivery.
- On the other hand, if the social video source and receivers are not in the same cell, but in a nearby cell, we can exploit the X2 interfaces of 4G eNBs to efficiently reroute the video packets. As shown in Fig. 3c, after receiving the uplink video packets from the video content generator, using the X2 interface, the source eNB (seNB) can reroute these video packets to the target eNBs (teNBs) of the receiving cell. The teNB, in turn, will transmit the video packets in the downlink to the video receivers. The system can bypass the traversal of video packets along the seNB → core network → video server → core network → teNB routes, thereby reducing video packet delay and jitter.
- Finally, as shown in Fig. 3d, if the social video source and receivers are in distant cells across different EPCs, we can explore LTE's S1 interfaces, as well as inter-EPC (core network) links. Using S1 interfaces, the seNB can route the video packets to the source SAE-GW (in the source core network). The source SAE-GW uses the inter-EPC links to reroute packets to the target SAE-GW (in the target core network). The target SAE-GW, now uses S1-interfaces to reroute the packet to the teNB. Thus, although the video receivers are in distant cells (across different core networks), next generation cellular networks can still avoid the external network,

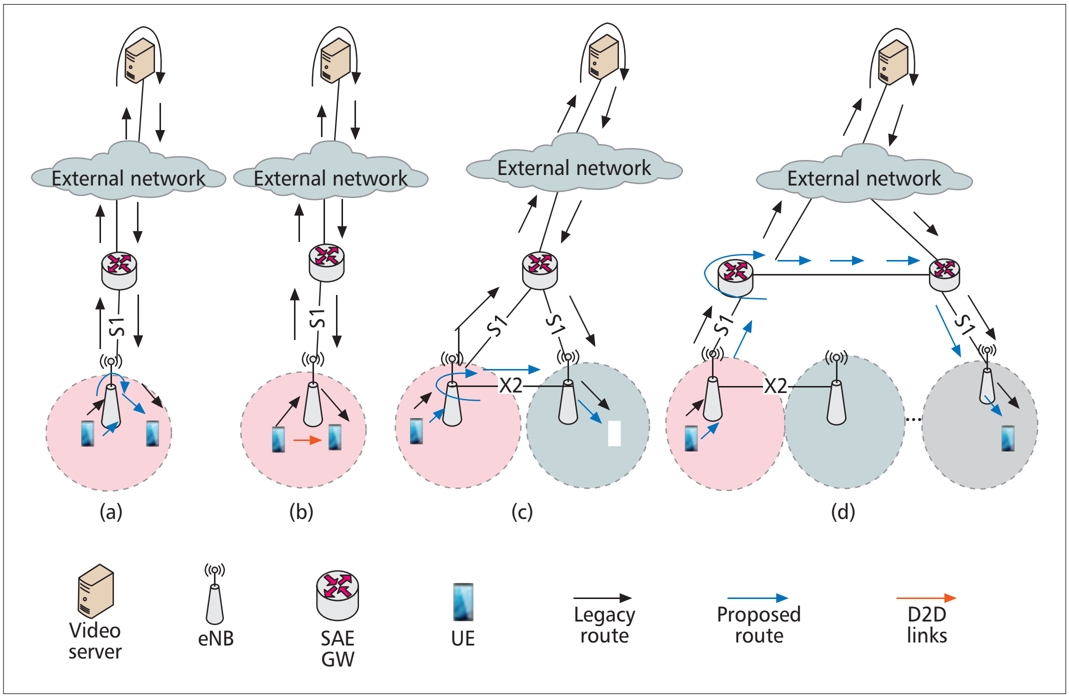

Figure 3. Scenarios in NGCN architecture for distributing social video streams where the sender and recievers belonging to a sender's social group are spread across different cells: a) video source and destination in the same cell; b) video source and destinations with D2D communications links; c) video source and destinations in different cells fo same core network; d) social video source and destinations in different core networks.

The NGCN options involve unicast video transmission between the video content producer and receiver. However, unicast video sharing incurs separate wireless radio resource consumption for every video receiver. Naturally, with a resource constrained cellular systems, this significantly reduces the cell capacity, measured in terms of number of receivers supported.

relieve the video server, and achieve significant improvements in social video sharing performance.

Note that the social network of the video content producer can be geographically spread over a large region, spanning multiple cells and core networks. Hence, in a real system, streaming user generated video content can encompass all four scenarios. While in traditional video transmission schemes the video server is responsible for all video transcoding, we consider that, as roles merge, the MNOs can equip eNBs with basic video transcoding and adaptation features. In this design, as transcoding workload is transferred to the eNBs from the content provider, power consumption at content providers will decrease at the cost of higher consumption at the eNBs. But overall reduction in network traffic should be beneficial in terms of total power consumption. Also, low-power video transcoding techniques should help in reducing the energy footprint for streaming.

Another practical concern relates to the use of location information of users by the MNOs. In the proposed architecture, MNOs do not need to share the location information with the content providers. Thus, no additional vulnerability is introduced, as compared to the privacy issues identified by Hahn *et al*. [12].

Next Generation Multicast for Social Video Sharing

The NGCN options involve unicast video transmission between the video content producer and receiver. However, unicast video sharing incurs separate wireless radio resource consumption for every video receiver. Naturally, with resource constrained cellular systems, this significantly reduces the cell capacity, measured in terms of number of receivers supported. For example, in a 20 MHz 2 × 2 multiple-input multiple-output (MIMO)-based 4G LTE systems, the theoretical peak data rates are 75 Mb/s in UL and 150 Mb/s in DL. Thus, to share a ~ 2 Mb/s high definition (HD) video, the theoretical maximum cell capacity is upper bounded by $\lfloor 75/2 \rfloor = 37$ video receivers. With multiple senders, spread across different locations of the cell, as well as non-video traffic workload, the actual cell capacity of a real cellular network would be much lower.

In order to improve the cell capacity for video sharing, NGCNs need to explore efficient user-initiated video multicast. Note that eMBMS [9] have already been standardized from Third Generation Partnership Project (3GPP) LTE Release 11.0 onward. However, legacy eMBMS systems currently support only server-based broadcast and multicast services across multiple users. This eMBMS in NGCNs are expected to gradually evolve to incorporate user-initiated video multicast for cell capacity improvement in social video sharing.

As shown in Fig. 4a, in this user-initiated multicast, the video sender and receivers form multiple multicast groups across different cells. Instead of multiple unicast connections, a sender can use a single uplink connection with its source eNB, which will multicast the video packets to the group of receivers within its coverage area. The source eNB also sends the video packets to the target eNBs over X2 interfaces or S1-SAE-

Typically, in a deployed network, the network vendor and the operator perform the cell planning and multicast group design by choosing a suitable worst channel condition. Further optimization is possible by designing multiple multicast groups within cells by grouping UEs with similar channel conditions.

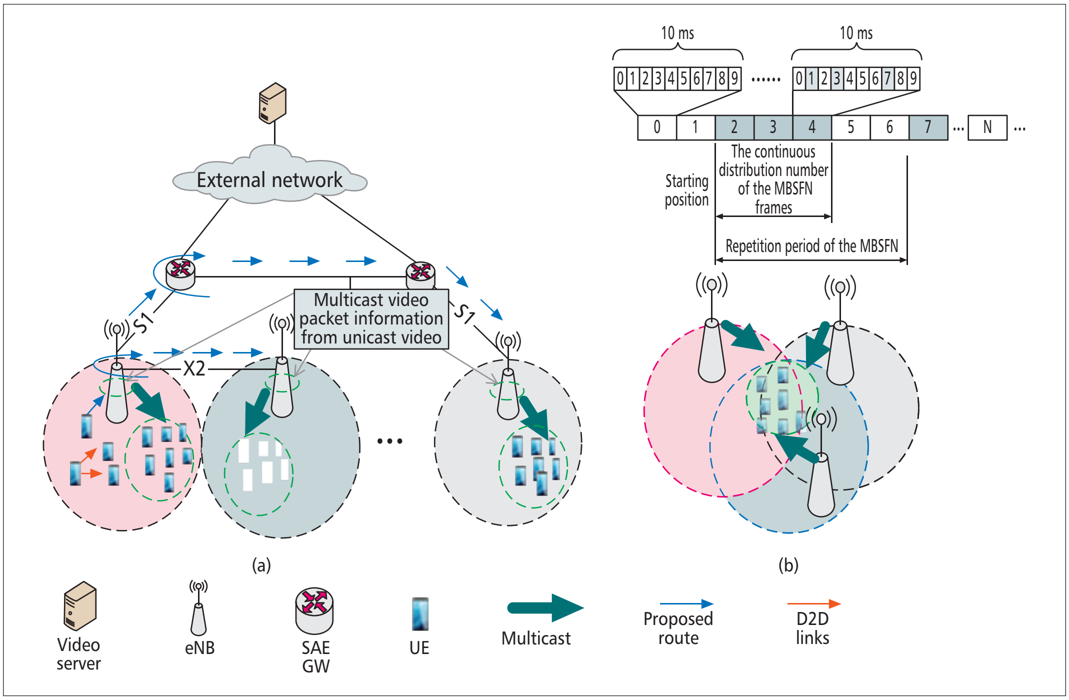

Figure 4. Use of multicast features in NGCNs, which allows efficient infrastructure resource usage to stream live video from a sender to its social group of receivers: a) social video sharing exploring user-initiated multicast; b) exploiting MBSFN for social video sharing.

GW interfaces. The target eNBs multicast the video packets to respective social groups within its coverage area. As multicast inherently shares radio resource among the receiver groups, this will significantly increase the network capacity of social video sharing. However, as legacy point-to-multipoint multicast involves multiple receivers, the eNB typically uses the user with the worst RF condition to determine the transmission rate. Selecting the transmission rate with the worst RF condition, can affect the QoE of UEs with good channel conditions. But, the trade-off is paid by supporting larger number of users in the multicast group. Typically, in a deployed network, the network vendor and the operator perform the cell planning and multicast group design by choosing a suitable worst channel condition. Further optimization is possible by designing multiple multicast groups within cells by grouping user equipments (UEs) with similar channel conditions.

Furthermore, NGCNs are evolving to exploit the MBSFN. As shown in Fig. 4b, MBSFNs enable multiple neighboring eNBs to cooperate for video packet transmissions to the same multicast group. Now, to the video receiver, transmissions received from multiple eNBs appear as a single transmission, subject to multipath propagation. This overcomes the shortcomings of legacy point-to-multipoint multicast by combining simultaneously received signals from different eNBs and transforming the corresponding portion of the destructive interferences into constructive ones (i.e., gain). Naturally, it improves the overall RF conditions experienced by all the social video receivers, especially the receivers at the cell edge. Thus, the difference between the best and worst RF conditions are largely reduced. Improvement in RF conditions enable the eNB to use less radio resource for the same video transmissions, thereby increasing the capacity even more. As shown in Fig. 4b, a 10 ms LTE MAC frame is made up of 10 1-ms subframes. Out of these 10 subframes, up to maximum 6 subframes could be reserved for eMBMS. Now, neighboring eNBs collaborate to form a cooperative downlink transmission frames at a regular interval, called the repetition period of an MBSFN.

PERFORMANCE EVALUATION

In this section we first discuss our simulation platform, major simulation parameters, and assumption. Subsequently, we show the simulation results with “user-initiated” unicast social video sharing. Finally, we extend our simulation to demonstrate user-initiated multicast for social video sharing.

In order to validate our proposed framework, we have developed an OPNET-based realistic urban LTE network model, involving multiple EPCs and eNBs spread across different cities. Physical parameters and an urban macro LTE channel model, specified in 3GPP physical layer (PHY) specifications [13] are used. Table 1 highlights the major LTE system and radio parameters used by us. The cell capacity is evaluated using standard video formats, like standard definition (SD), HD, full HD (FHD), and quadruple HD (QHD), with 1, 2, 4, and 8 Mb/s rates, respectively. Apart from the video bit rate and capacity experiments, we model two users sharing live HD social video streams at 2 Mb/s rate, simultaneously with 8 receivers (i.e., a total of 16 video receivers). These eight receivers are uniformly distributed across four scenarios (same cell, D2D, different cell, and different core), mentioned in the previous section, such that each scenario consists of two video receivers. We have considered social video streams of 5 min duration, as shown by Shen *et al.* to be the typical size of social video shares [14]. We also consider a set of new QoE metrics, which are considered to be more effective in capturing user experience [15]. These QoE metrics are explained below:

- *Playback start time* refers to the delay before a video stream starts playback.
- *Total rebuffering time* is defined as the total intermediate buffering time experienced after initiating the video playback session.
- *Rebuffering frequency* calculates the total number of intermediate buffering events or pauses due to buffer overrun that happen during a video playback.

Figure 5a shows the streaming video bit rate supported with two video sources transmitting to an increasing number of social video receivers spread across different cells. With increasing receivers, the supported bit rate starts dropping, thereby degrading the video quality. With our proposed video routing solution for NGCN, it is possible to support video bit rates 30 percent higher than those in the existing network for the same number of receivers. This is possible since the bottleneck between the eNB and the content provider is avoided in our scheme.

Figure 5b demonstrates that intelligent video traffic rerouting can reduce the packet jitter of HD video streams from 70 ms (median value) to 28, 20, 11, and 8 ms for users who are spread across different core networks, different cells, same cells, and D2D users, respectively. Note that when the stream is routed through the content provider, the jitter for users, irrespective of their proximity to the sender, will be similar.

Figure 5c shows that NGCNs can improve HD video playback start time from 5.9 s to 4.8, 3.8, 2.7, and 2.5 s for users across different core networks, different cells, same cells, and D2D users, respectively. Figure 5d shows how total rebuffering time increases with HD video playback. In a 5 min social video, legacy sharing experiences almost 1 min of total rebuffering time. On the other hand, total video rebuffering time reduces to 20 s even when the receiver is farthest from the sender, which is a 66 percent improvement. When the receiver is within the same cell and using D2D communication, the rebuffering time reduces to less than 10 s.

It is important to note that rebuffering time does not indicate the number of times there was a buffer overrun during viewing, and the user had to wait for rebuffering. Rebuffering leads to stalls during playback and is a bigger source of annoyance that can make users abort the stream. Hence, besides total rebuffering time, the number of rebuffering events is also an important video QoE metric. Figure 5e depicts that in the same 5 min HD video playback, a legacy system incurs around 20 rebufferings. On the other hand, depending on the receivers' locations, NGCNs can reduce rebuffering events to as low as six when the receivers can use D2D communication. Both the total rebuffering time and number of rebuffering events reduce with receiver proximity.

LTE radio access network models	
LTE network operating frequency	2 GHz
Channel bandwidth	20 MHz
LTE channel model	Urban macro [13]
Penetration loss (*l*)	20 dB
Cell radius (*R*)	500 m
Attenuation factor	$l + 37.6\log_{10}R$
Path loss compensation	0.8
eNB system models	
eNB's max. Tx power	43 dBm [13]
eNB's idle power	0.19 dBm [13]
Mobile's max power	20 dBm
Video Quality and BitRates	
Standard definition	1 Mb/s
High definition	2 Mb/s
Full high definition	4 Mb/s
Quadruple high definition	8 Mb/s

Table 1. LTE radio and system parameters.

It is important to note that rebuffering time does not indicate number of times there was a buffer overrun during viewing, and the user had to wait for rebuffering. Rebuffering leads to stalls during playback and is a bigger source of annoyance that can make users abort the stream.

Finally, Fig. 5f shows the cell capacity of social video sharing with a predefined video quality for all four types of video mentioned in Table 1. It points out that by exploring user-initiated multicast features, point-to-multipoint eMBMS and MBSFN can increase the cell capacity by almost 9 and 12 times, respectively, while maintaining the same video quality and user perceived QoE metrics for SD, HD, FHD, and QHD quality video. eMBMS achieves this significant capacity gain by transmitting a single uplink stream from a video source to the eNB and subsequently exploiting downlink resource sharing by multicast video packets. MBSFN further increases this capacity by exploring cooperation among multiple neighboring eNBs.

CONCLUSION

Lack of information sharing across content providers and mobile network operators can lead to suboptimal quality of experience for users. With the growing focus on video streaming in social networks, network traffic is poised to surge significantly. There have been many proposals that aim to improve video QoE using implicit performance indicators, like buffer status and channel conditions. However, cross-provider collaboration can

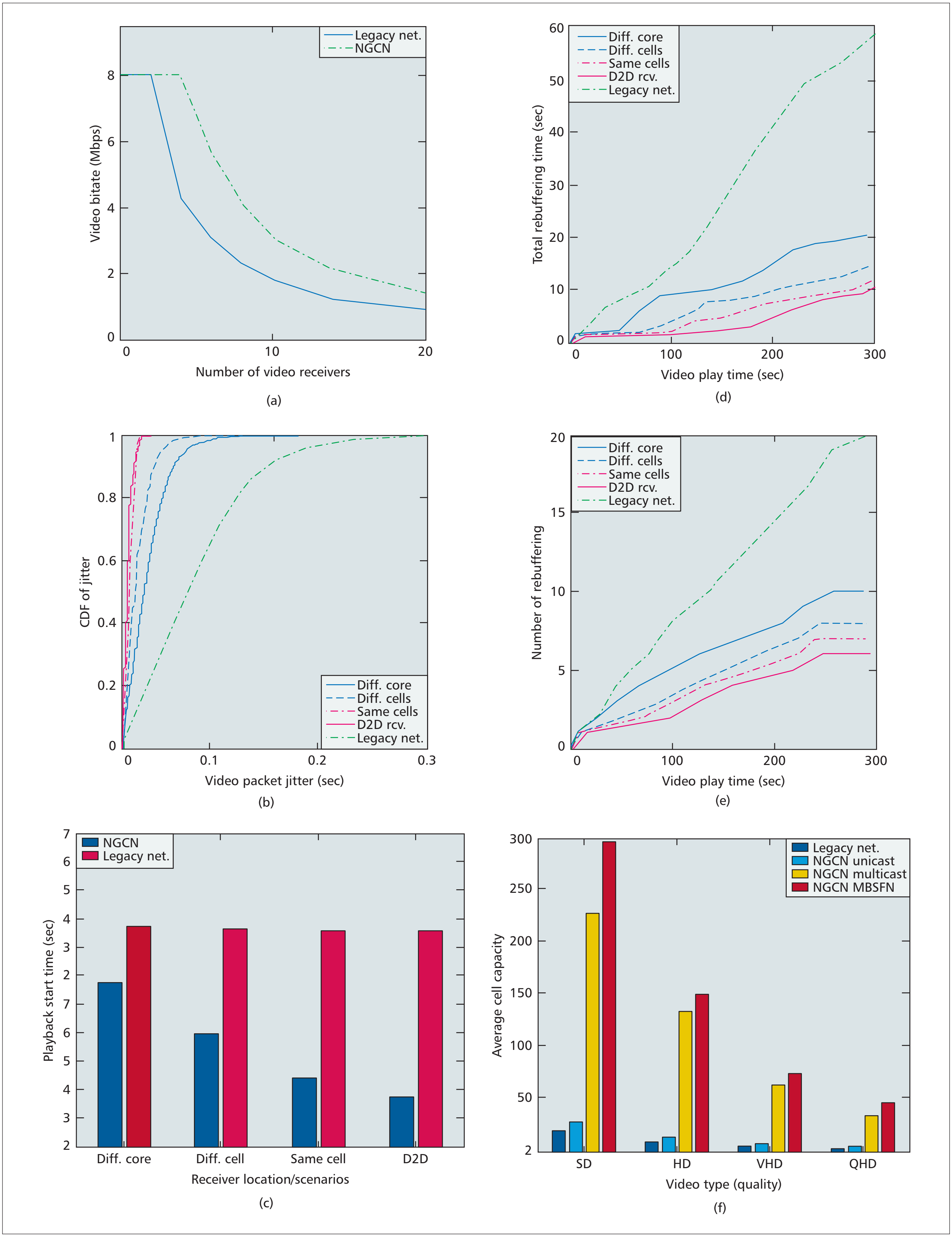

Figure 5. Simulation results showing the impact of location based re-routing of live social video streams. We show how different user perceived QoE metrics, viz. bitrate, jitter, start time, rebuffering time, and rebuffering events, are affected in different scenarios that represent different user locations. a) Video bitrate (quality); b) video jitter; c) playback start time; d) rebuffering time; e) rebuffering events; f) video sharing capacity.

lead to significant gains. In this article, we show that location information of the sender and receiver can be effectively utilized by MNOs for live streaming in mobile-device-centric social network sharing. Using simulation experiments, we show that routing live streams through the MNO infrastructure can significantly improve QoE with respect to supporting higher bit rate streams, lower jitter, reduced video playback start time, and smoother playback. The content provider can act as the controller that initiates the connection and shares the stream information with the MNO. The MNO leverages the proximity information of users to deliver live streams in an effective manner by routing through its nodes, which bypass the content provider network. We have also highlighted how features such as D2D can play an important role in video streaming in next generation cellular networks.

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