

以及 802.11ac 物理及链路层的技术改进也需要新的链路层自适应调制编码机制.新的物理及链路层技术进展可以通过与应用层、接口能耗特点相结合加以体现.与此同时,目前主要的多路径传输相关研究主要还是基于蜂窝网络和 WiFi 网络两大类的无线接入技术开展研究,新的底层接入技术层出不穷,如毫米波通信、电力线通信等,虽然已经有少量研究将这些底层接入技术纳入到多路径传输当中,如文献[98,99],未来仍有待于进一步加强.

2) 与新型网络技术的深入融合

为了应对上层多种多样的业务需求,5G 网络中采用基于 SDN/NFV 的网络切片技术,将物理网络切分为适合不同应用特点的网络切片.网络运营商需要根据其需要定义一系列的切片,而终端也需要根据其自身业务特点在切片之间进行选择^[100].与此同时,具备多接口的终端还能同时感知到多个运营商不同的网络切片,需要根据上层业务特点以及网络切片的负载状态进行合理的选择和数据分配.

3) 面向 360° VR/AR 视频应用的多路径传输

随着用户观看的角度的不同,360° VR/AR 视频应用将不同的视频流呈现给用户,从而带来更好的用户体验.这类应用的推出带来了网络更高的带宽和时延需求.利用多路径传输进行 360° VR/AR 视频的传输,能够通过有效聚合多条链路的带宽来满足其对网络更高的需求.同时,360° VR/AR 视频应用在视频编码方式^[101]以及用户体验方面的特点,也给多路径传输带来了新的优化空间.

4) 多层之间优化方案的协同

根据目前综述的相关文献,相关应用层和节能的优化主要还是应用层、传输层以及链路层之间的相互协同,与网络层的协同较少,没有有效地发挥网络层的优势和特点.例如,对于具有广播特性的网络(如无线 mesh 网络)而言,能够通过网络编码来进一步提高传输性能和可靠性.网络层多路由特性、组播/广播等特点,都应当能够通过与其他层改进方案的协同来进一步提升多路径传输的性能.

在多路径传输性能评估方面,需要在实际环境中进行全面的测量与分析.目前,关于多路径传输测量,相关研究采用的主要是安卓和笔记本终端,并通过安装 MPTCP 协议的现有实现进行测量与分析,如文献[82,91,102].本文中综述的大部分论文的相关验证或者是在仿真环境中进行的,或者是在人为设定链路参数的半实物环境中进行的,还缺乏有真实流量的环境的验证.与此同时,iphone 从 ios 11 开始搭载 MPTCP 协议,这也为在 iphone 上进行多路径传输的测试提供了可能.

7 总 结

本文首先从端到端多路径传输的基本功能出发,分析了其面临的主要挑战;然后,从体系结构各层的功能特点及其与多路径传输基本功能的关系着手,并考虑了将节能作为新的优化要素,对近年来利用跨层信息的多路径传输相关研究进行了较为系统和全面的比较和分析.

通过比较可以发现,多路径传输的基本功能的实现离不开各层信息的获取和协同,多路径传输能够感知到的信息越多,它能够带来的优化空间也就越大.本文还结合当前体系结构各层的研究热点对未来研究趋势进行了展望,为相关研究人员下一步研究的开展提供了一个可供参考的思路.

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