灵活高效传感和动态可靠路由则源于集中控制方式,有效增强了网络管理能力(SDWSN 处理流程步骤 5),进一步展示了高效管理和动态感知等优异性能.

(1) 异构快速互连

异构快速互连是 SDN 与 WSN 结合的初衷和根本原因,也是案例优势体现的关键,对灵活高效传感和动态可靠路由具有基础支撑作用.

在部署分布式 WSN 的情况下,智能小区安防监测系统和公共安全监测系统均按照自身分布式原则进行管理,无法通过消防部门或消防车辆的配置管理实现两者的直接连通,因此,居民小区的火情状态数据仅能通过消防部门转递到消防车辆上.

而在部署 SDWSN 时,控制面可直接对数据面中传感节点进行快速有效的配置管理.消防部门从监控服务器中获取智能小区安防监测系统和公共安全监测系统的基本信息后,依据相关策略(可由应用面提供)规划出两者互连的最优配置,包括待配置传感节点集合和配置参数集合,最后以控制命令方式下发,从而快速实现两套不同的安全系统之间的互连.

(2) 灵活高效传感

火情状态的灵活高效传感是有效提高现场消防人员救援效率的重要基础,也是面向应用提供按需传感服务的重要体现,包括监测范围和传感精度两个方面.

- 在监测范围上,SDWSN 可以由消防车辆上的传感控制节点进行配置和控制,从而及时将着火区域的传感节点纳入监测范围,甚至可扩展至公共安全监测系统中相关传感节点,一方面,通过扩大传感范围来支持对着火区域的实时跟踪;另一方面,通过调整传感角度或节点位置来快速消除传感覆盖空洞,防止着火区域内部未被传感的情况出现.
- 传感精度主要与传感节点覆盖重数和传感频率有关,覆盖重数和传感频率越高,传感精度就越高.因此,消防车辆中的传感控制节点可对着火区域传感节点进行传感角度和频率的调整,实现对关键部位的重点监控,比如小区幼儿园、配电室、卧室等,为救援人员提供更为精确的辅助信息.

(3) 动态可靠路由

火情状态的动态可靠路由指传感节点监测到火情状态数据后实时更新至消防车辆的过程,是提高火灾救援效率的重要支撑,路由传输的时效性和可靠性是关键.

通过两套安全系统之间的快速互连,火情状态数据直接通过传输时间最短的路径 D 发送,相比其他更新方式,极大地节省了传输时间,同时,也有效节约了传感节点的能量,可为救援人员提供更快速、更持久的信息支持.

考虑到火灾对传感节点的破坏,部分火情状态路由路径可能中断,因此通过动态配置传感节点流表,设计“一主多备”的数据传输路径,并尽量使火情状态数据绕开火灾中心区域,减少路由路径中断概率,在必要时,可实时下发新的流表规则来重置流转发,从而实现更为可靠的火情状态递送.

综上,由消防联动应用案例可以发现,SDWSN 相对分布式 WSN 具有更强的灵活性和适应性.在快速地连通异构无线传感器网络的基础上,通过灵活高效传感和动态可靠路由实现对火情状态采集和传输的全过程高效可靠处理,极大地提升了消防救援效率.因此,SDWSN 可以更好地满足实际需求,应用前景更为广阔.

4 总结与展望

目前,IoT,CPS 等的发展与应用日趋火热,WSN 与 SDN 的结合使感知物理世界的需求可以更好地被满足,针对 SDWSN 的研究也正在如火如荼的进行.因此,本文首先综述了目前学术界诞生的大量 SDWSN 架构,同时,依据控制器部署方式将其分为单控制器部署、水平多控制器部署和层次化多控制器部署这 3 类.在此基础上提出了 SDWSN 通用架构,并分别对应用面、控制面和数据面进行了阐述.然后,结合实际应用背景和 SDN 主要特性,针对动态高效传感、安全可靠传输等 SDWSN 两大核心功能,从异构互连、资源管理、可靠控制、网络安全这 4 个方面对学者的研究成果进行了梳理,并给出了研究成果汇总图.最后,以消防联动案例详细对比分析了 SDWSN 的优势和前景所在.相信在不久的将来,SDWSN 将取代分布式 WSN,迎来快速发展的春天.

目前,有线网络中的SDN技术发展仍不甚成熟,将SDN应用于WSN中所引入的挑战同样也不容忽视,未来SDWSN的研究中以下几个方面可能值得关注.

(1) SDWSN标准制定

众所周知,标准制定会极大地促进行业发展.SDN 技术标准已经得到世界各大标准化组织的关注,如 ONF, IETF,ITU,ETSI 等[106].SDWSN 作为 SDN 应用于 WSN 的实例,SDWSN 标准首先应该遵循 SDN 标准的基本原则,其次也应充分考虑 WSN 自身的本质特性,最后还需要尽量满足未来发展需求.

(2) 共存过渡方案设计

纵观 SDWSN 的发展及应用,分布式 WSN 将与 SDWSN 在相当一段时间内共存[107].从市场应用角度考虑,为使 SDWSN 可以更好地融入市场,降低产业界转型的成本,要求 SDWSN 发展初期与分布式 WSN 兼容.因此,研究由分布式 WSN 向 SDWSN 的共存过渡方案具有较高的实用价值.

(3) 集中控制程度权衡

WSN 中无线链路所引入的通信时延与 SDN 中时延敏感的可靠控制存在着天然的矛盾[40,87],因此在SDWSN 中,过度的集中控制并不一定能带来网络性能的提升.随着传感节点处理能力的提升,适当将时延敏感且可以下放的控制功能交由传感节点负责,合理权衡控制面的集中控制程度,是一个值得深入探讨的问题.

(4) 网络合作覆盖探索

网络覆盖是网络传感服务质量的重要保证[28,76].源于支持异构网络互连共享,SDWSN 在通过异构网络合作提升网络覆盖性能方面具有较大的潜力.基于此,重点研究如采用 ZigBee,6LOWPAN 等技术的异构网络之间的合作覆盖策略,关注用户感兴趣的区域,可面向应用提供针对性更强的高质量传感服务.

(5) 网络能量供应优化

能量供应是从根本上解决 WSN 能量受限的重要方法,包括无线充电技术[26,108]、环境能量收集技术[109,110]等.然而,受限于应用环境和部署成本,目前传感节点无线充电或太阳能、风能收集等均存在效率较低的缺陷.因此,借助控制面全局视图,SDWSN 可以综合考虑能量消耗与能量供应,并可通过环境能量预测、能量消耗及供应规划等方法来实现全网能量收集和传输的最优化,因而值得进一步深入研究.

(6) 网络安全增强研究

当前,互联网安全威胁频现的主要原因在于发展初期对安全问题考虑较少[111].因此,SDWSN 需要尽可能早地开展网络安全增强技术研究,将安全作为发展甚至是未来标准化的重要因素.目前,在具体安全技术上,异构网络互连共享下的传感节点接入控制、网络隐私保护以及控制策略冲突检测等方面有待进一步研究.

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黄美根(1990－),男,湖南娄底人,硕士,CCF 学生会员,主要研究领域为无线传感器网络,软件定义网络,网络安全.

黄一才(1985－),男,讲师,主要研究领域为无线网络安全.

郁滨(1964－),男,博士,教授,博士生导师,主要研究领域为信息安全,无线网络安全,视觉密码.

周伟伟(1990－),男,博士,主要研究领域为无线传感器网络,网络安全.