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EXAMINING THE RELATIONSHIP BETWEEN CONVERGED-NETWORK ARCHITECTURE AND REMOTE GRASSFIRE ALERT TRANSMISSION DELAY IN SOUTHEAST COLORADO: A CYBERSECURITY AVAILABILITY STUDY

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ABSTRACT

Aim/Purpose	The purpose of the present study was to examine the relationship between a converged wireless-sensor/cellular network architecture and cybersecurity, in terms of transmission delay, to deliver remote grassfire alerts to firefighters in Southeast (SE) Colorado.
Background	Agriculture, rural communities, a thriving cattle industry, and a kaleidoscope of flora and fauna characterize the plains of SE Colorado. Unfortunately, the hot and dry climate of SE Colorado combines with the ever-expanding wildland-urban interface (WUI), presenting an enormous grassland fire risk. A review of the literature revealed a deficit of research that addressed the alerting mechanism between remote WSN-based fire detection and response forces.
Methodology	The present research pursued a converged-network solution from two courses of action (COA) to address the wildfire risk. COA-A and COA-B coupled the ZigBee-Pro and ZigBee-IP WSN protocols, respectively, with the 4G-LTE infrastructure prevalent throughout SE Colorado to bolster alert information availability. Following construction of the simulation models, the Ostinato packet generator performed 194 end-to-end transmissions with each COA to ascertain the better-performing solution in terms of network transmission delay.
Contribution	The study's findings offer a starting point for subsequent research that will lead to a proposal for SE Coloradans – and beyond – to help bridge the gap between detective WSNs and the response forces that can subdue remote grassfires. To

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the extent the authors could surmise, the current research effort was the first to model and simulate a one-way, UDP-based wireless network that comprised a WSN node, two WSN-Cellular gateway designs, and several 4G-LTE infrastructure components. The simulated environment also measured and compared the end-to-end network transmission delay for two unique solutions, including the convergence process within the WSN-Cellular gateway.

Findings COA-B proved the superior solution with a 16.2% delay improvement over COA-A. An independent-samples t-test confirmed the statistical significance between the results' means.

Recommendations for Practitioners COA-B offered a remote SE Colorado grassfire alerting solution that minimized network transmission delay and maximized alert payload to responding firefighters. However, the generalizability of the current research's results indicates utility for firefighters providing overwatch to grasslands throughout the world – wherever valuable grasslands intersect with a 4G-LTE on-ramp. Within the United States and outside SE Colorado, 4G-LTE from multiple carriers exists throughout the Great Plains. U.S. industries, communities, and ecosystems that rely on the abundance of Great Plains grasslands abound and feature use cases ripe for benefit from the present research.

Recommendations for Researchers Additional studies could offer more depth and recommend solutions to bolster the alert mechanism between fire detection and response capabilities. The literature is teeming with research that improves the efficacy of fire-detective WSNs. However, the dearth of practice-oriented research that delivers an alert to firefighters in SE Colorado and elsewhere warrants further work on top of the present study.

Impact on Society The study's findings need not apply only to grassfires. Much research and residual challenges exist on the topic of forest and wildfire alerts throughout the world. Although the generation mechanisms may differ, propelling an alert over available infrastructure – 4G-LTE or other – offers a workable solution to ensure timely response to unsolicited fires.

Future Research The current research's incremental construction of delay measurements for COA-A and COA-B encourages the creation of an end-to-end model in network simulators such as NS3 or OMNeT++. A network simulation framework like OMNeT++ would allow a more comprehensive representation of wireless channel effects on overall delay. The creation and testing of a physical COA-B prototype would provide a proof of concept for the current study. Future work could bridge the gap between any varietal of remote sensor network and the audience that consumes sensor data anywhere in the world.

Keywords wireless sensor network (WSN), wildfire, alert, converged network, simulation

INTRODUCTION

The large, open expanses of the Colorado Great Plains east of Interstate 25 belie the mountain lover's paradise that many may picture of the Centennial State (Griffiths & Rubright, 2018). Instead, the rural, sparsely populated counties of Southeast (SE) Colorado boast 360-degree horizons uninterrupted by even the meekest of hills (DOLA, 2019; Griffiths & Rubright, 2018). The ocean of SE Colorado plains extends east from the Rocky Mountain foothills of Trinidad, Walsenburg, and Cañon City to the Kansas border.

Despite the sparsity of SE Colorado (Atlas Big, 2018), industry and agriculture abound (Hurt, 2020). SE Colorado is one of the most productive agricultural areas in the state, part of a $3.7 billion cattle market that is the fourth largest exporter of beef in the nation (CCA, 2021). Many of the United States' wheat, melons, onions, and peppers spring from the almost 3,000 farms in SE Colorado.

In addition to life-sustaining industries, the SE region of Colorado constitutes a piece of the North American Great Plains (CSFS, 2020a; Luaenroth et al., 1999). Numerous SE Colorado plant and animal species help define the Great Plains ecology (Carlier et al., 2009; LandScope Colorado, 2020). Presently, the agricultural industry and SE Colorado community development live in concert with the Great Plains prairie ecosystem (CSFS, 2020a). The demarcation line between agriculture and ecology manifests as the wildland-urban interface (WUI; Carlier et al., 2009).

Unfortunately, the ever-expanding WUI (Carlier et al., 2009) plays host to a common and potentially devastating threat to the industries of SE Colorado and the Great Plains: uncontrolled grassland fires (CSFS, 2020b; Lynn & Campbell-Hicks, 2020). Exacerbating the grassland fire threat in SE Colorado is the lack of a reliable end-to-end alerting mechanism that can detect and inform firefighters of a remote fire (Devadevan & Sankaranarayanan, 2017; Grewe, 2020; nPerf, 2021). Since humans detect most wildfires (Rego & Catry, 2006), the low number of SE Colorado inhabitants per square mile (Atlas Big, 2018) further compounds the region's wildfire risk. Thus, the current study proposed a solution that coupled remote fire detection (Kadir et al., 2018) with the communication infrastructure prevalent in SE Colorado counties (nPerf, 2021) to help reduce the delays in alerts firefighters receive.

A review of works related to remote wildfire detection with wireless sensor networks (WSN) (Aksamovic et al., 2017; Kadir et al., 2018) revealed a gap in the literature regarding the propagation of alerts from detective WSNs to responding firefighters. The present research effort was a quantitative experimental simulation study that explored the convergence of WSNs and mobile cellular networks (MCN; Ismaili et al., 2019). Specifically, the current study paired the internal network protocols of ZigBee – a popular WSN protocol (Ahmad & Hanzálek, 2018) and 4G-LTE (Cox, 2012) to help address the alerting deficit characteristic of remote SE Colorado (nPerf, 2021; Svaldi, 2019). The prompt detection of fires and receipt of future fire alerts by firefighters will help stem the destruction wild grassland fires can exact (CSFS, n.d.; Hung et al., 2015).

PROBLEM STATEMENT

The problem addressed by the present study was the relationship between a converged wireless-sensor/cellular network architecture and cybersecurity, in terms of transmission delay, to deliver remote grassfire alerts to firefighters in SE Colorado had not been identified (Crosby & Vafa, 2013; Grewe, 2020; Lynn & Campbell-Hicks, 2020; Svaldi, 2019; Swain et al., 2018). Grewe (2020) and Lynn and Campbell-Hicks (2020) detailed grassfires and brushfires in SE Colorado that burned thousands of acres; threatened homes, buildings, livestock, valuable natural resources; and nearly destroyed historical landscapes in 2020. Svaldi (2019) described the technology gap residents of the Colorado Great Plains experience due to the lack of fiber-based broadband internet and 5G cellular services. Finally, Crosby and Vafa (2013) and Swain et al. (2018) highlighted the potential for future research to improve the network throughput/availability of converged WSNs and MCNs.

STUDY PURPOSE

The purpose of the present quantitative experimental simulation study was to examine the relationship between a converged wireless-sensor/cellular network architecture and cybersecurity, in terms of transmission delay, to deliver remote grassfire alerts to firefighters in SE Colorado. The research effort adopted the simulation method to perform relevant experiments (Salkind, 2012; Sekaran & Bougie, 2013). The study quantified the extent to which the manipulations of wireless network protocols affect transmission delay by way of an experimental design (Osborne, 2020). 388 individual experiments resulted in two groups of 194 data points for subsequent statistical analysis and comparison (Mills et al., 2006; Sekaran & Bougie, 2013).

The present effort's problem statement addressed an issue relevant to the *availability* pillar of cybersecurity's CIA triad (Qadir & Quadri, 2016). According to NIST (2021), availability is, in part, the *timely* access to information. Harris (2013, p. 159) added that availability ensures data and resources are readily accessible by information users for continued productivity. The current study resulted in a converged-network architecture that minimized the transmission delay between a remote grassfire detective system and the resultant alert's propagation to a fire station in SE Colorado. Therefore, the present research effort promoted information availability – i.e., cybersecurity (Harris, 2013; Qadir & Quadri, 2016) – that arrived from the reliable and timely delivery of remote grassfire detection alerts to firefighters.

The current research effort investigated the scenario of a fixed-position WSN-MCN gateway. Stationary gateways within the transmission range of a cellular tower represented a more suitable deployment use case for SE Colorado (Ismaili et al., 2019; Swain & Ray, 2020). Fixed gateways can more feasibly aid the conveyance of an alert from a remotely deployed fire detection WSN to the 4G-LTE infrastructure prevalent throughout SE Colorado (nPerf, 2021).

RESEARCH QUESTION AND HYPOTHESES

The current study's central research question was, what, if any, relationship exists between a converged wireless-sensor/cellular network architecture and cybersecurity, in terms of transmission delay, to deliver remote grassfire alerts to firefighters in SE Colorado? To help answer the research question, the present study defined two courses of action (COA) – A and B – that represented two unique converged-network solutions for simulation, analysis, and comparison. The better-performing COA in terms of network transmission delay, in seconds, resulted in a final recommendation to help reduce remote grassland fire alert delays received by SE Colorado firefighters.

COA-A converged the ZigBee-Pro WSN protocol (Franceschinis et al., 2013; Ismaili et al., 2019) with the 4G-LTE user equipment (UE) stack (Cox, 2012). COA-B converged the ZigBee-IP WSN protocol (Franceschinis et al., 2013; Varghese et al., 2015) with 4G-LTE. The review of literature revealed ZigBee-Pro and ZigBee-IP as two of the most popular WSN protocols.

The present quantitative inquiry leveraged two hypotheses upon which statistical analysis focused.

H_0: There is no statistically significant difference in the mean measured network transmission delay between COA-A and COA-B.

H_1: There is a statistically significant difference in the mean measured network transmission delay between COA-A and COA-B.

SIGNIFICANCE OF THE STUDY

The present study contributed to the remote wildfire alerting and converged-network body of knowledge in several ways. First, the current research effort addressed a practical problem in SE Colorado (Lynn & Campbell-Hicks, 2020; Svaldi, 2019; Swain et al., 2018). The literature review discovered no authors in the literature who studied a similar issue that affected the SE Colorado region. Second, this study proposed two novel converged-network protocols that uniquely implemented ZigBee and 4G-LTE from the physical through transport layers (Bora et al., 2014).

Third, and to the extent the present study could surmise, the current research effort was the first to model and simulate a one-way, UDP-based (Clark, 1988) wireless network that comprised a WSN node, two WSN-MCN gateway designs (Franceschinis et al., 2013; Osborn & Bennett, 2012; Swain & Ray, 2020), and several 4G-LTE infrastructure components (Cox, 2012; Tutorialspoint, 2020). The simulated environment also measured and compared the end-to-end network transmission delay for two unique solutions, including the convergence process within the WSN-MCN gateway. Total transmission time, in seconds, constituted the 388 simulation runs – i.e., samples – across two groups of data.

REVIEW OF THE LITERATURE

The study's review of the literature comprised three components. First, the literature review explored the importance of grasslands (Carlier et al., 2009; LandScope Colorado, 2020) and the destructive power of remote grassfires in SE Colorado (Grewe, 2020; Lynn & Campbell-Hicks, 2020; Markus, 2022). Second, the literature review showcased works highlighting WSN-based wildfire detection and the increase in destructive risk resulting from the delayed receipt of wildfire alerts by firefighters (Georgiades et al., 2019; Xu et al., 2018). The sparse and underdeveloped SE Colorado communication infrastructure between remote grassfire detective technology and fire stations exacerbates risk (Crosby & Vafa, 2013; DOLA, 2019; nPerf, 2021). The literature review's latter component described research that offers fertile ground for a converged WSN-MCN solution (Swain & Ray, 2020; Swain et al., 2016).

Around the world, grasslands occupy roughly 8.5 billion acres of land - more than twice the amount of arable land (Carlier et al., 2009). The utility of grasslands is second to none, with a broader range of applications than any other crop worldwide. North American grassland soils store large amounts of organic material (Luaenroth et al., 1999), promoting water retention and the provision of vital plant nutrients (Anderson & Coleman, 1985).

In addition to their ecology and natural beauty, grasslands serve as an agricultural haven and primary source of food for herds of wild herbivores and domesticated grazing animals (Carlier et al., 2009). Grasslands also act as carbon repositories – or sinks – thanks to their assortment of grass, herb, and legume species. Additionally, grasslands prevent erosion, attract multiple species of migratory birds, provide habitats for small prairie animals, and store nitrogen (Bengtsson et al., 2019; Carlier et al., 2009). As a result, many of the world's grasslands enjoy a symbiosis with the environment, except those grasslands that experience intensive use (Carlier et al., 2009).

The eastern third of Colorado occupies the North American Great Plains, a distinctive ecosystem of grassland prairie that extends from Canada's far northern reaches to the south of Texas and east from the Rocky Mountain foothills (CSFS, 2020a). Today communities, economies, development, and agriculture exist alongside the prairie ecosystem and have helped shape SE Colorado's grasslands into their current form (CSFS, 2020a). Pasturelands for cattle grazing abound in the Colorado shortgrass prairie system (LeCain et al., 2002). Private citizens own roughly 87% of Colorado's shortgrass prairies, and the owners devote much of their shortgrass holdings to agricultural production (LandScope Colorado, 2020).

With the ever-increasing Colorado population, development continues to expand and push the WUI boundary into prairies and forest landscapes (CSFS, 2020b). The dry climate, increasing number of homes, and heightening traffic in the formerly wild areas of the WUI also increase the risk of accidental fires. Numerous and repeating fires, coupled with poor management of fire aftermath, cripple nature and humankind alike. SE Colorado is no stranger to wildfires. The adverse aftermath of wildfires in SE Colorado (Lynn & Campbell-Hicks, 2020; Markus, 2022) inspired the converged-network, remote grassfire alerting solution that subsequent sections of the present study proposed (Swain & Ray, 2020).

The ephemeral presence of volunteer firefighters at a rural fire station lends to longer response times for remote wildfires (CSFS, n.d.). Quick-moving surface fires in SE Colorado prairies typically find a home amongst short, improved, and agricultural grasses. Grass prairies that sport tall and unmanaged grasses cultivate a massive stash of intensely burning fuels (CSFS, 2020b).

Wind-driven grassfires in SE Colorado – and other Great Plains locations throughout the United States with hot, dry, windy climates – carry the potential to spread with blinding velocity (Markus, 2022): as fast as two meters per second (Cheney & Gould, 1995). According to CSFS (n.d.), the first few minutes of a grassfire represent the most critical moments in saving one's home. Fast response to remote wildfires is paramount to reducing their destructive risk. However, timely alerts precede firefighters' ability to respond (Rego & Catry, 2006).

Wireless sensor networks (WSN) are ideal tools to address SE Colorado's grassfire threat thanks to their ability to detect fires (Kadir et al., 2018) and the ease with which one can deploy them (Swain et al., 2016). WSNs form the essential elements of many wildfire detection and alerting systems (Kaur & Manshahia, 2017). However, WSNs exhibit some limitations for end-to-end fire alerting – i.e., propagating an alert from the point of detection to a response force (Wagoner, 2021). Sensors exhibit resource constraints such as power and transmission range, which encourage localized wireless connections only with neighbors (Kaur & Manshahia, 2017).

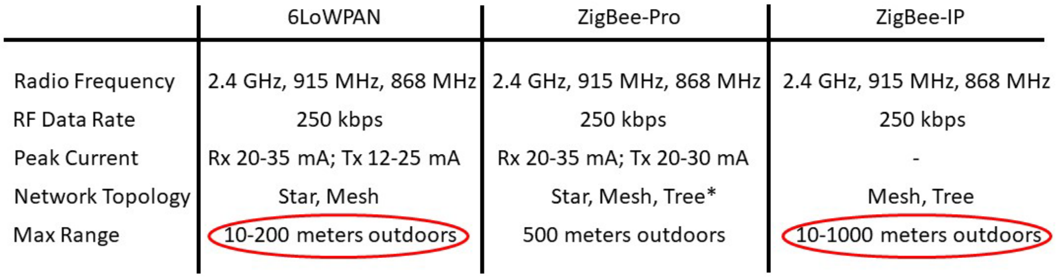
The thrust of the present research effort's method centered around the convergence of WSNs and MCNs (Zhao et al., 2019). An MCN tower within range of a fire-detection WSN's last-hop node offers the ability to propel a remote fire alert to firefighters. MCNs boast wide network coverage areas, robust endpoints, and resilient networks with many capabilities (Swain et al., 2016). The 4G-LTE infrastructure prevalent throughout rural SE Colorado (nPerf, 2021), complemented by its extensive transmission range (Cox, 2012, p. 302), provided an ideal mechanism for WSN-MCN convergence.

The current research converged the ZigBee-Pro (Franceschinis et al., 2013) and ZigBee-IP (Varghese et al., 2015) WSN protocols with 4G-LTE to reduce network transmission delay between fire detection and response entities in SE Colorado. Many integrated WSN-MCN networks feature mobile terminals or mobile stations as the MCN dual-mode gateway (Xia et al., 2012; Zhang et al., 2012). However, the current study followed a unique departure from WSN-MCN solutions in the literature by incorporating a fixed MCN gateway to reduce the solution's complexity. The convergence of heterogeneous protocols between WSNs and MCNs must balance the need for performance with network complexity and energy consumption (Swain & Ray, 2020).

Three popular WSN protocols throughout the literature include 6LoWPAN, ZigBee-Pro, and ZigBee-IP (Franceschinis et al., 2013; Ismaili et al., 2019; Varghese et al., 2015). The ZigBee-Pro protocol stack distinguishes itself from 6LoWPAN and ZigBee-IP at all layers above the data link layer (Franceschinis et al., 2013). However, 6LowPAN and ZigBee-IP bear close resemblances at all protocol stack layers (Ismaili et al., 2019; Varghese et al., 2015). Therefore, analysis of 6LoWPAN ceased in the current quantitative experimental simulation study due to Ismaili et al.'s (2019) conclusions of 6LoWPAN's inferior outdoor transmission performance.

The rural expanses of SE Colorado demanded the maximization of transmission range (Wagoner, 2021). Table 1 lists some specifications of the 6LoWPAN, ZigBee-Pro, and ZigBee-IP WSN protocols. The sparsely populated stretches of SE Colorado counties (Atlas Big, 2018; Svaldi, 2019) necessitate WSN protocols with high transmission ranges (Farsi et al., 2019). ZigBee-Pro carries a potential maximum transmission range over twice that of 6LoWPAN, and ZigBee-IP boasts five times 6LoWPAN's maximum range (Ismaili et al., 2019).

Table 1. 6LoWPAN and ZigBee, adapted from Ismaili et al. (2019) and Li et al. (2010).



	6LoWPAN	ZigBee-Pro	ZigBee-IP
Radio Frequency	2.4 GHz, 915 MHz, 868 MHz	2.4 GHz, 915 MHz, 868 MHz	2.4 GHz, 915 MHz, 868 MHz
RF Data Rate	250 kbps	250 kbps	250 kbps
Peak Current	Rx 20-35 mA; Tx 12-25 mA	Rx 20-35 mA; Tx 20-30 mA	-
Network Topology	Star, Mesh	Star, Mesh, Tree*	Mesh, Tree
Max Range	10-200 meters outdoors	500 meters outdoors	10-1000 meters outdoors

The current study filled a crucial gap in the remote wildfire detection and response literature. Very little, if any, research explores the problems associated with the alerting mechanism that connects WSN detections of remote grassland fires and the firefighting professionals responding. The literature lacks a detailed analysis of and solutions for problems regarding the wireless network's physical and logical segment connecting remote grassfire detections to responder forces. Specifically, the current study addressed network transmission delays associated with converged WSN-MCN networks (Crosby & Vafa, 2013; Swain & Ray, 2020; Xu et al., 2018). Narrowing the research gap addressed the risks of grassland fires in the rural counties of SE Colorado.

METHOD

Quantitative experimental simulation defined the current study's methodology, design, and method, respectively. The present effort recommended a converged-network solution from two that most effectively reduced remote grassfire alert delays in SE Colorado. Subsequent paragraphs describe the two converged WSN-MCN candidate solutions.

The present research effort analyzed two potential courses of action (COA) – A and B – for follow-on statistical analysis that resulted in a final recommended COA for best performance in network transmission delay to address the research question. The study measured the transmission delay between a WSN node and the packet data network (PDN) gateway (P-GW) within the 4G-LTE evolved packet core (EPC; Tutorialspoint, 2020). COA-A's design converged the ZigBee-Pro WSN protocol (Ismaili et al., 2019) with the 4G-LTE cellular protocol stack (Cox, 2012; Crosby & Vafa, 2013) for simulated testing. COA-B converged the ZigBee-IP WSN protocol (Ismaili et al., 2019; Osorio et al., 2016; Varghese et al., 2015) and 4G-LTE (Cox, 2012; Crosby & Vafa, 2013) for simulated testing.

The current study employed the tactic of Osborne (2020) to designate the independent variable (IV) and the dependent variable (DV). The architecture of the remote grassfire alerting network segment between the last-hop WSN node and the S5/S8 interface at the 4G-LTE P-GW (Cox, 2012) constituted the IV. The IV varied in terms of the protocol stack within the last-hop WSN node and the WSN-MCN gateway under observation.

The end-to-end delay, in seconds, from the last-hop fire detection WSN node to the P-GW's S5/S8 interface (Cox, 2012) served as the DV. The DV varied as a function of the WSN node and WSN-MCN gateway protocol configurations – a component of the IV – and the simulated, noise-based packet delivery rate, which was a characteristic of the study's wireless network channels (Lee et al., 2007; Soijoyo & Ashari, 2017).

POPULATION AND SAMPLE

The study leveraged the Ostinato packet generation platform (Ostinato, 2020) to build and test COA-A and COA-B. The converged network for this study featured a solution that incrementally traversed the first four protocol stack layers of both a WSN used to detect fires and 4G-LTE that could potentially carry alerts from the WSN to firefighters (Bhatia et al., 2018; Swain & Ray, 2020; Xu et al., 2018). Protocol layers from lowest to highest included the physical, data link, network, and transport layers (Bora et al., 2014).

The statistical power calculation software G*Power (Faul et al., 2007) provided the research effort's sample size of 388 total simulation runs, or 194 runs per proposed solution. G*Power requires several statistical metrics and descriptive inputs before it calculates sample size. The G*Power inputs included *Test family*, *Statistical test, Type of power analysis, Tail(s), Effect size d, a error probability, Power (1-β error probability),* and *Allocation ratio N2/N1.*

In selecting the G*Power inputs, the present study borrowed from Knopik (2020) and Osborne (2020) who performed quantitative studies like the current study. Wagoner (2021) offers a detailed explanation of the selection of each G*Power input parameter. The present research effort performed a *t*-test treatment on the means of numerical results – i.e., end-to-end delay – from two different proposed solutions. A comparison of results determined the current study's final recommendation for reducing the alert delay between the remote grassfire sensing capability and firefighters in SE Colorado.

DATA COLLECTION INSTRUMENTATION AND PROCEDURES

Economics played an integral part in the decisions which determined the Colorado markets that received 5G networks first (Svaldi, 2019). The limited propagation distance of 5G signals placed the rural Colorado markets – and the vast distances that separate them – low on the priority list of potential future customers. Therefore, rural areas such as the SE Colorado counties must continue to rely on 4G-LTE coverage (nPerf, 2021; Svaldi, 2019). The current and future status of the 4G-LTE service in SE Colorado thus inspired the present study's practical application of a converged-network solution based on the 4G-LTE protocol and architecture (Cox, 2012).

Figure 1 illustrates the test environment for the current simulation research effort. The dashed box in Figure 1 encompasses all the present study components to build the simulation model. The study simulated only the WSN and 4G-LTE components necessary to measure the transmission delay from the last-hop WSN node to the 4G-LTE P-GW (Cox, 2012; Crosby & Vafa, 2013). The labels t_i and t_e in Figure 1 represent the initial and ending times, respectively, for the simulated end-to-end transmission delay measurement. The simulation model also included a noise channel (Soijoyo & Ashari, 2017) to mimic the delay that results from lost packets over noisy media.

For the current study, network convergence via protocol conversion occurred in the WSN-MCN gateway (Swain & Ray, 2020). To minimize network delay (Xu et al., 2018) and processing complexity (Kaur & Manshahia, 2017; Shan et al., 2016), COA-A and COA-B designs relied on one-way, connectionless fire alert transmissions from remote WSNs to firefighters. The WSN-MCN gateway in the study also remained stationary instead of exercising mobility, significantly reducing the computational overhead of both the gateway and the detective WSN (Shan et al., 2016; Swain et al., 2018; Zhang et al., 2012).

Following the suggestions of, in part, Crosby and Vafa (2013) and Swain and Ray (2020), the current study proposed courses of action that manifested the one-way transmission of packets from the remote detective WSN through the 4G-LTE architecture to firefighters. Layer 2 of the 4G-LTE Uu interface – MAC, RLC, and PDCP sub-layers (Cox, 2012) – occupies 442 total bytes of header and payload, 42 bytes and 400 bytes, respectively (Swain & Ray, 2020). An IEEE 802.15.4 packet that arrives from a WSN consumes 127 bytes (Crosby & Vafa, 2013; Howitt & Gutierrez, 2003; Swain & Ray, 2020). Therefore, a WSN's IEEE 802.15.4 packet can fit inside the payload of the 4G-LTE Uu interface MAC layer (Cox, 2012; Swain & Ray, 2020).

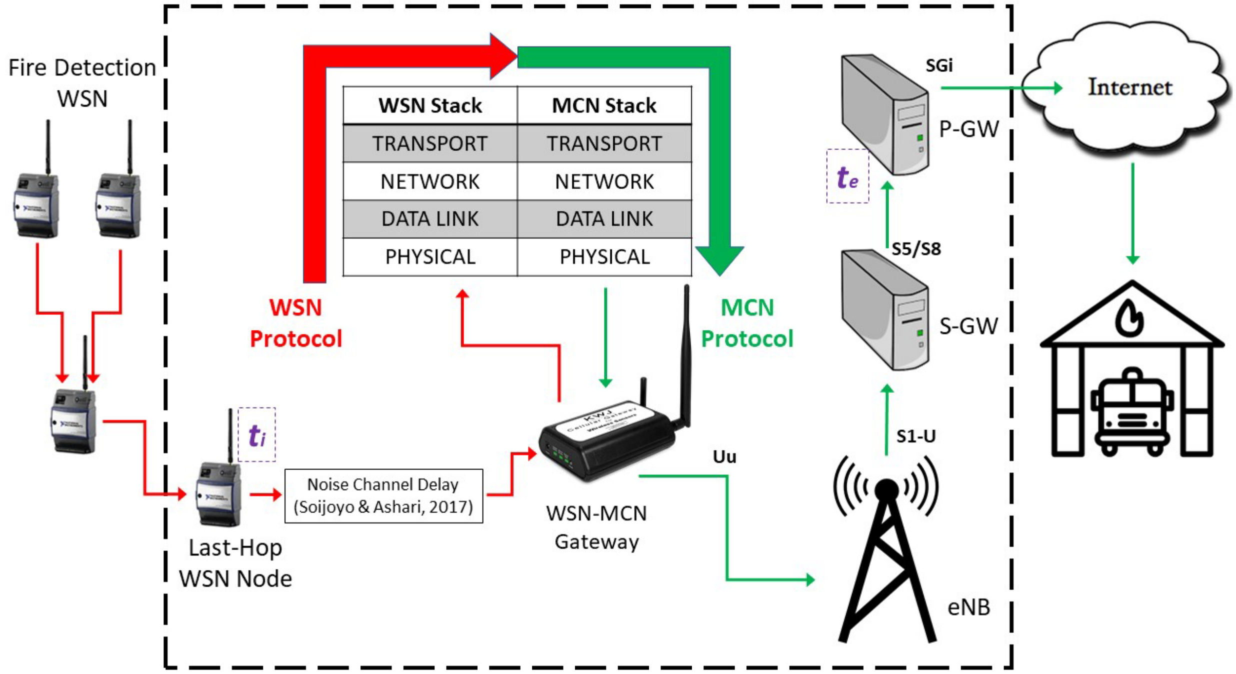


Figure 1. Conceptual architecture to simulate and test network latency, $t_e - t_i$.

Figure 2 and Figure 3 provide the conceptual models of COA-A and COA-B the current research effort simulated, respectively. The left third of Figure 2 illustrates the protocol stack (ZigBee, 2015) of a ZigBee-Pro WSN-generated alert arriving at the WSN-MCN gateway. The ZigBee-Pro standard does not allow direct communication with an IP network, i.e., the Internet (Ismaili et al., 2019). Therefore, the ZigBee gateway (Osborn & Bennett, 2012) functions as the WSN-MCN gateway in Figure 2 to shape a ZigBee-Pro packet into something ingestible by the TCP/IP 4G-LTE network.

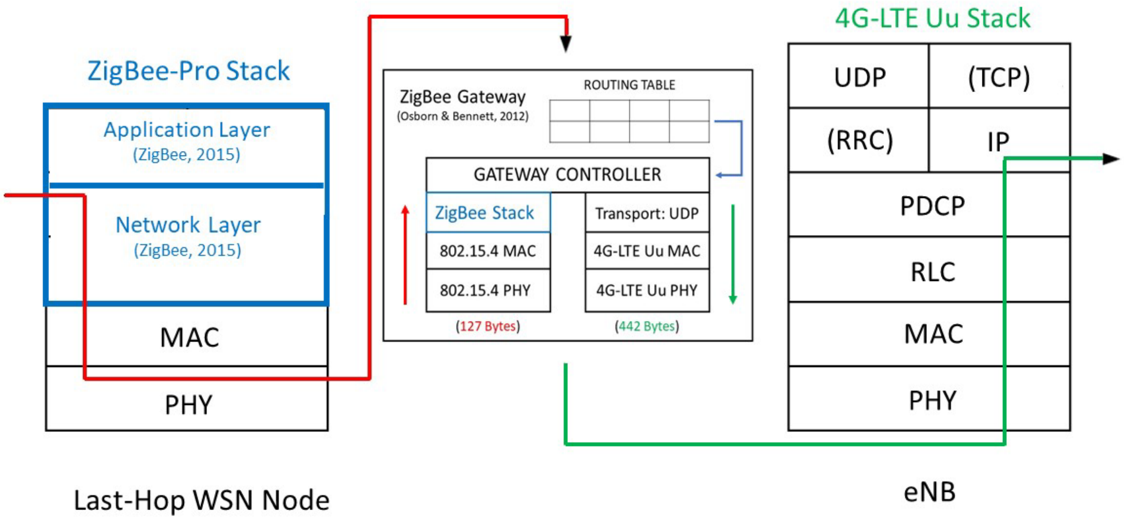


Figure 2. COA-A, ZigBee-Pro and 4G-LTE; adapted from Swain and Ray (2020).

Throughout the literature, many studies discuss the need for a ZigBee gateway to allow communication between ZigBee-Pro nodes and devices on a TCP/IP network (Borean & Pastrone, 2008; Franceschinis et al., 2013; Ismaili et al., 2019). However, very few offer details of a gateway's internal transformative mechanism that allows the successful exposure of ZigBee-Pro to a TCP/IP environment. Osborn and Bennett (2012) provided a patent for the ZigBee gateway that inspired the current study's adaptation in Figure 2. Finally, the right third of Figure 2 shows the propagation of a WSN-generated alert across the 4G-LTE environment up through the transport layer – i.e., UDP (Cox, 2012).

Figure 3 showcases the present study's COA-B. COA-B defined the convergence of the ZigBee-IP WSN protocol (Franceschinis et al., 2013; Ismaili et al., 2019; Varghese et al., 2015) and 4G-LTE (Cox, 2012). Unlike ZigBee-Pro, ZigBee-IP can interact with a TCP/IP network with minimal intervention (Ismaili et al., 2019). The center third of Figure 3 features the conceptual detail of the WSN-MCN gateway. The current study replicated IPv4 encapsulation within the WSN-MCN gateway that allowed seamless communication with the 4G-LTE protocol stack (Swain & Ray, 2020).

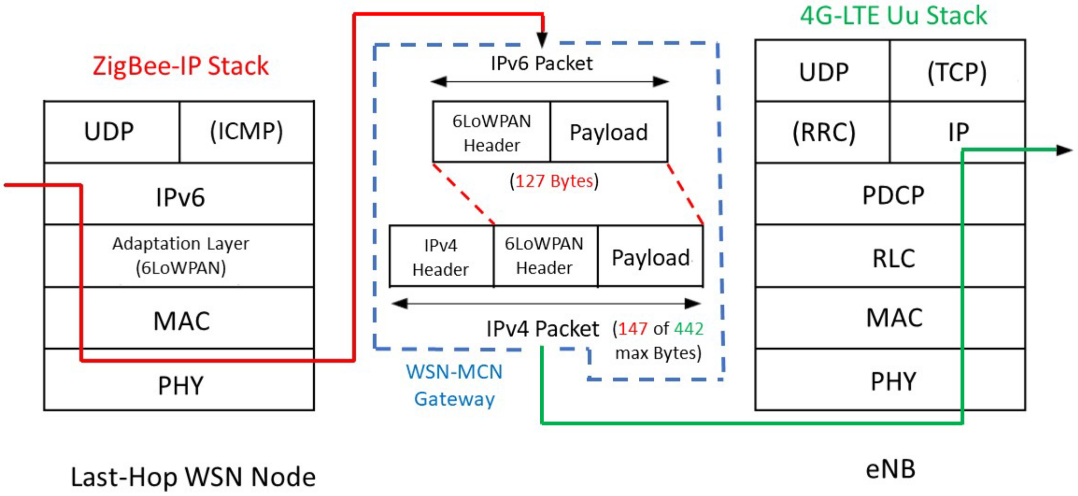


Figure 3. COA-B, ZigBee-IP and 4G-LTE; adapted from Swain and Ray (2020).

Both COAs leveraged the user datagram protocol (UDP; Clark, 1988) as the post-convergence-gateway transport layer solution. UDP is a connectionless protocol – i.e., the source simply sends its payload to a destination without further bi-directional coordination to guarantee the payload's delivery. Unlike the transport control protocol (TCP), UDP relinquishes reliability for speed, leaning on the underlying network layers' aptitude for reasonable assuredness of payload conveyance.

From the current study's perspective, a fire station receiving an alert from a remotely deployed WSN would have to participate in a reliable connection across the 4G-LTE and converged-network infrastructures if the link relied on TCP as the transport protocol. The present research effort evaluated that scenario as impractical when designing COA-A and COA-B. Additionally, UDP's reduced overhead offers as much as 31% more payload than TCP (Franceschinis et al., 2013; Wagoner, 2021), which could allow the implementation of more detailed remote grassfire alerts.

DATA ANALYSIS PROCEDURES

From Figure 1, the present study modeled the last-hop WSN node, the WSN-MCN gateway, cellular tower (eNB), and the serving gateway (S-GW) using the Ostinato packet generation software. Figure 4 shows a simplified version of the experimental simulation model, akin to Crosby and Vafa's (2013) tight coupling method. Results represented the end-to-end transmission delay from the WSN node through the WSN-MCN gateway and the 4G-LTE interfaces to the P-GW: t_e - t_i.

In Figure 4, t_i represents the initial network transmission time, the precise moment the last-hop WSN node generates its alert signal. At the opposite end of the model, t_e denotes the ending network transmission time – the moment, in seconds, when the P-GW receives the alert at its S5/S8 interface

(Cox, 2012). The current study also factored in the noise channel delay as a component of the overall end-to-end delay according to the methods of Soijoyo and Ashari (2017).

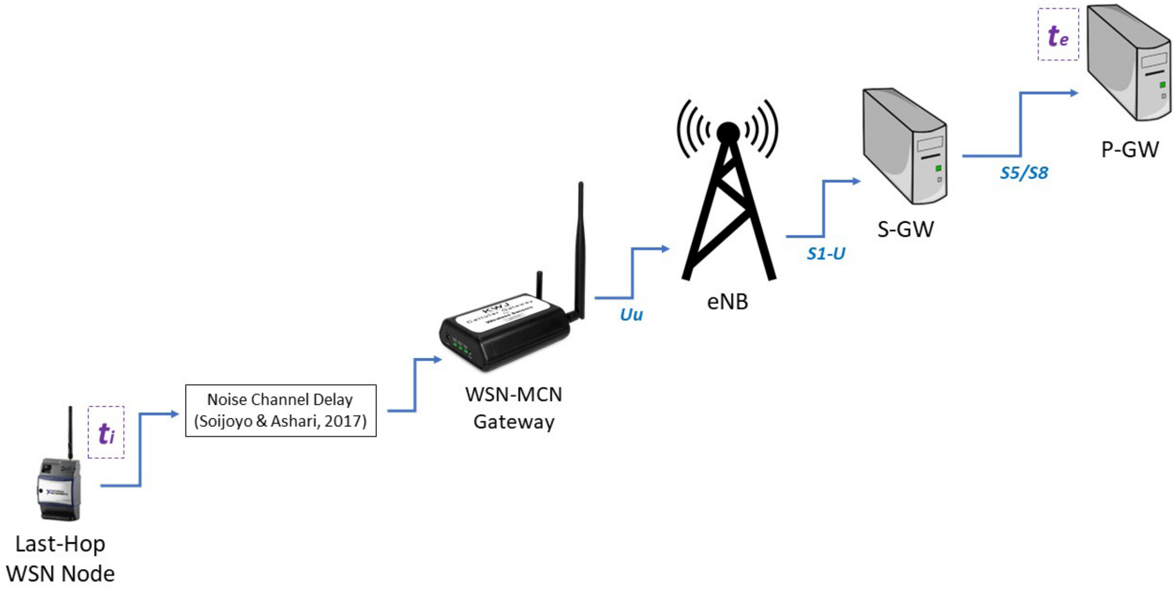


Figure 4. Components and interfaces for simulation in Ostinato; adapted from Figure 1.

The present study leveraged a Fourier-like approach (Hoffmann, 1997) with its atomization of COA-A and COA-B into individual transmissions bounded by unique protocol stacks within component devices (Wagoner, 2021). The experimental simulation study performed 388 transmissions within the model – 194 for COA-A and 194 for COA-B. Post-simulation analysis recorded the two groups of 194 results and subjected each of the DVs to statistical analysis with IBM® SPSS® Statistics for Windows® (Osborne, 2020; Tudor, 2014). Collected measurements received descriptive (Thompson, 2009) and inferential (Bettany-Saltikov & Whittaker, 2014) statistical analysis.

Descriptive analysis determined mean values for each group of results along with standard deviations, skewness of outputs, and kurtosis (Blanca et al., 2013; Osborne, 2020; Tudor, 2014). Normality is not the norm with real data (Blanca et al., 2013). Therefore, the current study relied upon a Shapiro-Wilk test (Shapiro & Wilk, 1965) to describe normality ($p > .05$) within the two groups of results for COA-A and COA-B (Osborne, 2020). Levene's Test for equality of variances (Brown & Forsythe, 1974) helped found the efficacy of a t-test for non-normal datasets. Afterward, an independent-samples t-test determined the need to accept or reject any of the study's hypotheses.

ASSUMPTIONS

The present research rode atop several key assumptions. First, the study assumed reliable connectivity between the 4G-LTE P-GW – starting at the SGi interface (Figure 1) – and the firefighter who would receive the remote grassland fire alert. Internet connectivity was outside the scope of the current research effort, and therefore the research assumed reliable communication therein. Second, the research assumed a WSN that transmits a grassfire detection alert in SE Colorado is secure and reliable since myriad security issues threaten the efficacy of WSNs (Tomić & McCann, 2017).

Additionally, the current effort assumed the last-hop node of a grassfire detection WSN possesses a transmission range and resides in a location that allows successful communication with the WSN-MCN gateway. If a WSN successfully detects a remote grassfire and generates an alert, the alert must reach the on-ramp to the 4G-LTE infrastructure, which the WSN-MCN gateway would represent. Likewise, the study assumed a reliable link between the WSN-MCN gateway and 4G-LTE eNB, i.e., the cellular base station. The wireless connections between the last-hop WSN node, the WSN-MCN gateway, and the cellular tower must all provide enduring availability (NIST, 2021). Otherwise, the current study's model fails.

Finally, the current effort assumed microsecond (μs) precision with the Ostinato internal reference clock (Ostinato, 2020). All measurements in the **Findings** section that arrived from the Wireshark (Wireshark, 2021) packet capture software carried six decimal places of precision for time measurements. Analysis of delay leaned heavily on Ostinato's ability to initiate a new packet precisely one second after completing the previous packet's transmission. Therefore, μs consistency within the Ostinato packet generator reverberated throughout all subsequent measurements and calculations that led to the results for both COAs.

FINDINGS

The present study built COAs A and B within the Ostinato packet generation simulator (Ostinato, 2020; Patil et al., 2017). Each COA's model resulted in a total end-to-end delay measurement comprised of singular transmissions that reflected individual protocol stacks within each device. Eleven separate transmissions across nine unique protocol stacks and a noise channel (Soijoyo & Ashari, 2017) combined to form the complete end-to-end experimental simulation model for COA-A.

Nine separate transmissions across seven unique protocol stacks plus a noise channel (Soijoyo & Ashari, 2017) comprised the complete end-to-end experimental simulation model for COA-B. The final measurements resulted from the summation of individual sample transmissions – components of the complete end-to-end measurement. The following paragraphs provide additional details of the 388 transmission delay samples for COAs A and B in Table 2.

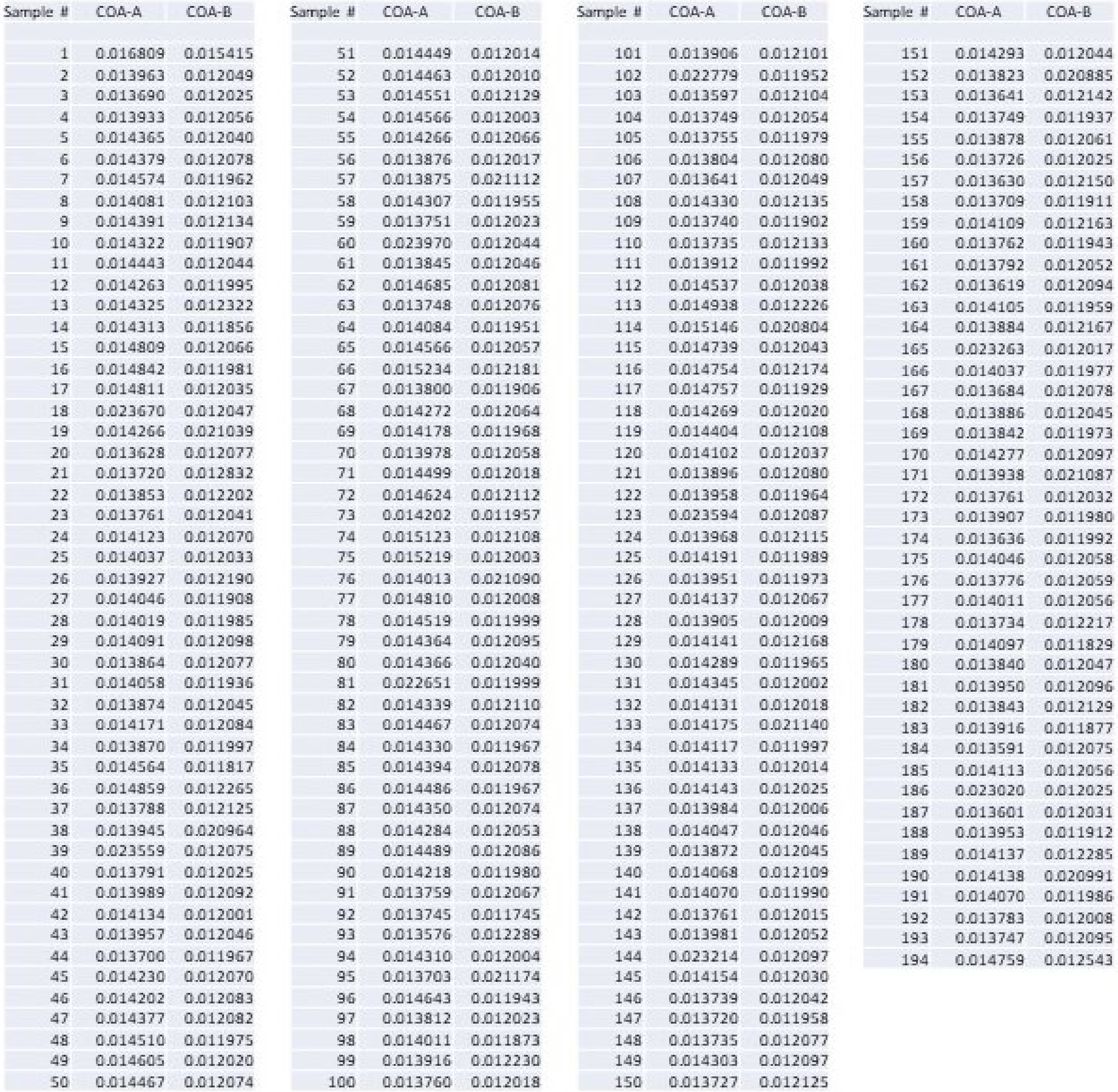
The current study simulated wireless sensor nodes with up to 1,000 meters of separation (Ismaili et al., 2019). Extrapolation of Soijoyo and Ashari's (2017) data via Microsoft® Excel® helped determine packet loss percentages for WSNs with one kilometer of distance between nodes. COA-A and COA-B modeled 500 meters and 1,000 meters of inter-node separation, respectively (Ismaili et al., 2019). The Excel® logarithmic extrapolation feature calculated a packet loss percentage (y) of 4.29% for COA-A and 5.08% for COA-B as a function of WSN node separation (x) with the equation,

$$y = 1.1315 * \ln(x) - 2.7377$$

The current effort's simulation integrated the packet loss predictions of Soijoyo and Ashari (2017), which manifested as 62% and 72% overall increases in sample end-to-end transmission time for COA-A and COA-B, respectively. Table 2 highlights the noise channel effects in COA-A's sample numbers 18, 39, 60, 81, 102, 123, 144, 165, and 186, which required roughly nine additional milliseconds of transmission (Silicon Labs, n.d.). Similarly, COA-B's sample numbers 19, 38, 57, 76, 95, 114, 133, 152, 171, and 190 reflected the 9 ms noise channel delays due to dropped packets and retransmitted packets (Soijoyo & Ashari, 2017; M. H. Wang et al., 2017).

For the present study's experimental simulation, noise channel packet losses of 4.29% and 5.08% translated to 9 and 10 lost packets over 194 samples for COA-A and COA-B, respectively. For simplicity, the simulation incorporated a lost packet once every 21 and 19 samples for the two COAs. Dropped packets conjured packet retransmission (M. H. Wang et al., 2017) which effectively doubled the noise channel time cost – from 9 ms to 18 ms (Silicon Labs, n.d.). COA-B's additional 500 m of separation (Ismaili et al., 2019) incurred approximately 2 μs of free-space propagation time (Stein, 2018). Since all transmission delay measurements retained six decimal places of precision, the present study's simulation model successfully factored the difference in WSN node separation that effected unequal propagation times between the two COAs.

Table 2. End-to-end transmission delay in seconds, COA-A and COA-B.



Sample #	COA-A	COA-B
1	0.016809	0.015415
2	0.013963	0.012049
3	0.013690	0.012025
4	0.013933	0.012056
5	0.014365	0.012040
6	0.014379	0.012078
7	0.014574	0.011962
8	0.014081	0.012103
9	0.014391	0.012134
10	0.014322	0.011907
11	0.014443	0.012044
12	0.014263	0.011995
13	0.014325	0.012322
14	0.014313	0.011856
15	0.014809	0.012066
16	0.014842	0.011981
17	0.014811	0.012035
18	0.023670	0.012047
19	0.014266	0.021039
20	0.013628	0.012077
21	0.013720	0.012832
22	0.013853	0.012202
23	0.013761	0.012041
24	0.014123	0.012070
25	0.014037	0.012033
26	0.013927	0.012190
27	0.014046	0.011908
28	0.014019	0.011985
29	0.014091	0.012098
30	0.013864	0.012077
31	0.014058	0.011936
32	0.013874	0.012045
33	0.014171	0.012084
34	0.013870	0.011997
35	0.014564	0.011817
36	0.014859	0.012265
37	0.013788	0.012125
38	0.013945	0.020964
39	0.023559	0.012075
40	0.013791	0.012025
41	0.013989	0.012092
42	0.014134	0.012001
43	0.013957	0.012046
44	0.013700	0.011967
45	0.014230	0.012070
46	0.014202	0.012083
47	0.014377	0.012082
48	0.014510	0.011975
49	0.014605	0.012020
50	0.014467	0.012074
51	0.014449	0.012014
52	0.014463	0.012010
53	0.014551	0.012129
54	0.014566	0.012003
55	0.014266	0.012066
56	0.013876	0.012017
57	0.013875	0.021112
58	0.014307	0.011955
59	0.013751	0.012023
60	0.023970	0.012044
61	0.013845	0.012046
62	0.014685	0.012081
63	0.013748	0.012076
64	0.014084	0.011951
65	0.014566	0.012057
66	0.015234	0.012181
67	0.013800	0.011906
68	0.014272	0.012064
69	0.014178	0.011968
70	0.013978	0.012058
71	0.014499	0.012018
72	0.014624	0.012112
73	0.014202	0.011957
74	0.015123	0.012108
75	0.015219	0.012003
76	0.014013	0.021090
77	0.014810	0.012008
78	0.014519	0.011999
79	0.014364	0.012095
80	0.014366	0.012040
81	0.022651	0.011999
82	0.014339	0.012110
83	0.014467	0.012074
84	0.014330	0.011967
85	0.014394	0.012078
86	0.014486	0.011967
87	0.014350	0.012074
88	0.014284	0.012053
89	0.014489	0.012086
90	0.014218	0.011980
91	0.013759	0.012067
92	0.013745	0.011745
93	0.013576	0.012289
94	0.014310	0.012004
95	0.013703	0.021174
96	0.014643	0.011943
97	0.013812	0.012023
98	0.014011	0.011873
99	0.013916	0.012230
100	0.013760	0.012018
101	0.013906	0.012101
102	0.022779	0.011952
103	0.013597	0.012104
104	0.013749	0.012054
105	0.013755	0.011979
106	0.013804	0.012080
107	0.013641	0.012049
108	0.014330	0.012135
109	0.013740	0.011902
110	0.013735	0.012133
111	0.013912	0.011992
112	0.014537	0.012038
113	0.014938	0.012226
114	0.015146	0.020804
115	0.014739	0.012043
116	0.014754	0.012174
117	0.014757	0.011929
118	0.014269	0.012020
119	0.014404	0.012108
120	0.014102	0.012037
121	0.013896	0.012080
122	0.013958	0.011964
123	0.023594	0.012087
124	0.013968	0.012115
125	0.014191	0.011989
126	0.013951	0.011973
127	0.014137	0.012067
128	0.013905	0.012009
129	0.014141	0.012168
130	0.014289	0.011965
131	0.014345	0.012002
132	0.014131	0.012018
133	0.014175	0.021140
134	0.014117	0.011997
135	0.014133	0.012014
136	0.014143	0.012025
137	0.013984	0.012006
138	0.014047	0.012046
139	0.013872	0.012045
140	0.014068	0.012109
141	0.014070	0.011990
142	0.013761	0.012015
143	0.013981	0.012052
144	0.023214	0.012097
145	0.014154	0.012030
146	0.013739	0.012042
147	0.013720	0.011958
148	0.013735	0.012077
149	0.014303	0.012097
150	0.013727	0.012125
151	0.014293	0.012044
152	0.013823	0.020885
153	0.013641	0.012142
154	0.013749	0.011937
155	0.013878	0.012061
156	0.013726	0.012025
157	0.013630	0.012150
158	0.013709	0.011911
159	0.014109	0.012163
160	0.013762	0.011943
161	0.013792	0.012052
162	0.013619	0.012094
163	0.014105	0.011959
164	0.013884	0.012167
165	0.023263	0.012017
166	0.014037	0.011977
167	0.013684	0.012078
168	0.013886	0.012045
169	0.013842	0.011973
170	0.014277	0.012097
171	0.013938	0.021087
172	0.013761	0.012032
173	0.013907	0.011980
174	0.013636	0.011992
175	0.014046	0.012058
176	0.013776	0.012059
177	0.014011	0.012056
178	0.013734	0.012217
179	0.014097	0.011829
180	0.013840	0.012047
181	0.013950	0.012096
182	0.013843	0.012129
183	0.013916	0.011877
184	0.013591	0.012075
185	0.014113	0.012056
186	0.023020	0.012025
187	0.013601	0.012031
188	0.013953	0.011912
189	0.014137	0.012285
190	0.014138	0.020991
191	0.014070	0.011986
192	0.013783	0.012008
193	0.013747	0.012095
194	0.014759	0.012543

The mean of COA-A's 194 end-to-end network transmission delay measurements was 14.554 milliseconds (ms). The mean of COA-B's 194 end-to-end measurements was 12.529 ms. Using the COA-B mean delay as the control (Foster, 2013), COA-A required 16.2% more time to traverse the simulated convergence gateway and 4G-LTE infrastructure than did COA-B.

The direct comparison of the COAs' means required the establishment of a statistically significant difference between the two sets of results (Osborne, 2020). To establish a statistically significant difference, the two COAs' results received descriptive statistical analysis (Salkind, 2012), a Shapiro-Wilk test for normality (Shapiro & Wilk, 1965), and finally, an independent-samples t-test (Laerd, 2021; Sekaran & Bougie, 2013). Wagoner (2021) provides details of the result groups' statistical analysis.

The higher complexity of COA-A's architecture contributed to its increased transmission delay. COA-A required two more individual transmissions to fully complete its end-to-end model, and the additional transmissions resided within the ZigBee gateway (Osborn & Bennett, 2012). One of the additional internal ZigBee gateway transmissions was *T4*, the routing table reference (Wagoner, 2021). The present study's simulation revealed *T4* incurred a time penalty of roughly 1.8 ms, approximately five times the delay of other transmissions throughout the COA-A end-to-end model. The routing table reference plus the second individual transmission accounted for the 2.025 ms higher average end-to-end delay of COA-A.

LIMITATIONS OF STUDY FINDINGS

The creation of the two simulation models for COA-A and COA-B revealed a practical limitation of the Ostinato packet generator for the present study. Ostinato did not support the simulation of the IEEE 802.15.4 physical and data link layers (Adams, 2006). Researcher correspondence with Ostinato's creator (Ostinato, 2020) confirmed the software's limitation. However, Ostinato did support the use of Ethernet II for the physical and data link layers. Ostinato also supported packet customization that allowed each COA to carry the requisite number of end-to-end bytes.

Another limitation of the study lied in the piecemeal approach of individual transmissions for end-to-end network delay measurements. The COA-A and COA-B performances relied on the summation of metrics at the device and protocol stack levels vice a continuous flow's single measurement from the last-hop WSN node to the P-GW inbound interface. Fourier Theory (Hoffman, 1997) supported the validity of atomizing COA-A and COA-B into their component transmissions. Although the incremental representation for end-to-end delay measurement may have lowered the analyses' realism (Rico & Merino, 2020), the segmentation of the simulation models simultaneously fostered a more granular and holistic understanding of each COAs' performance (Y. Wang, 2021).

Myriad environmental factors affect the propagation of electromagnetic waves. Some of the factors include signal frequency (Cummer, 2000), properties of the medium (Arecchi et al., 1969), modulation scheme (Du & Zhao, 2009), interference (Yang et al., 2010), and nearby material properties (Smith & Schurig, 2003). Simulations such as OMNeT++ provide robust considerations of medium and environmental effects on wireless channels (Mallanda et al., 2005; Varga & Hornig, 2008). As a configurable packet generator, Ostinato lacked the ability to simulate the full assortment of wireless channel phenomena in the transmission between the WSN node and the convergence gateway for both COAs. However, the manual implementation of Silicon Labs' (n.d.) experimental ZigBee behavior into the study offered a modicum of wireless noise channel realism that future studies can leverage.

INTERPRETATION OF STUDY FINDINGS

Despite the limitations, the present study produced results that pointed to a statistically superior course of action. COA-B's coupling of ZigBee-IP and the 4G-LTE infrastructure sprang from the application of a simulated convergence gateway with simpler internal workings than those of the ZigBee gateway (Osborn & Bennett, 2012; Swain & Ray, 2020). COA-B dropped more packets and traveled twice as far between nodes in the wireless channel, leading to overall average transmission delay increases (Silicon Labs, n.d.; Stein, 2018). However, the inclusion of routing table and gateway controller transactions within the ZigBee gateway (Osborn & Bennett, 2012) led to the additional 2 ms of average delay for COA-A over COA-B. Subsequent analysis proved statistical significance in the difference between the two COAs' mean delay measurements.

The better performance of COA-B helped achieve the current study's goal to recommend a novel or improved grassfire alerting mechanism that minimizes the delay between detection and alert reception by firefighters. Relative to Xu et al.'s (2018) six-minute window to alert firefighters, the two-millisecond performance improvement that COA-B exhibited is a very small amount of time. A COA-A-generated alert that reaches firefighters 2 ms later than COA-B's alert would garner no attention or realization. However, the aspects of COA-B that led to its reduced delay prove favorable for remote grassfire alerting in SE Colorado.

PRACTICE IMPLICATIONS OF STUDY FINDINGS

The current research effort's findings led to a recommendation of COA-B as the better solution for grassfire alerts in remote SE Colorado for three significant reasons. First, COA-B's use of ZigBee-IP promotes a larger WSN that can cover more of the SE Colorado Great Plains expanses with the same number of nodes that COA-A would require. Since ZigBee-IP WSN nodes can operate with twice as much inter-nodal distance as ZigBee-Pro nodes (Ismaili et al., 2019), a ZigBee-IP WSN can monitor four times the area of a comparable ZigBee-Pro WSN. Fewer WSN nodes monitoring the same swathe of grasslands for fire presents a better bargain for SE Coloradans.

Second, the convergence of 4G-LTE and a ZigBee-IP WSN – with its reduced cost compared to a ZigBee-Pro WSN – also boasts a simpler internal architecture (Swain & Ray, 2020; ZigBee, 2015). The IPv6-based ZigBee-IP protocol can communicate directly with the 4G-LTE infrastructure and the Internet via IPv4 encapsulation within the WSN-MCN convergence gateway (Osorio et al., 2016; Swain & Ray, 2020). ZigBee-IP WSNs eliminate the need for a ZigBee gateway with time-consuming internal routing table and gateway controller transactions. The relative simplicity of ZigBee-IP and 4G-LTE convergence promotes increased network throughput.

Third, COA-B proposed and tested upper-layer protocols that effected speed and data maximization. The use of UDP instead of TCP as the transport solution eliminated the need for time-consuming two-way handshakes and connection-oriented flows (Clark, 1988). The SE Colorado fire alerting use case established the scenario of one-way alert traffic between the detective WSN and the response parties. The lower overhead of UDP also provided additional room for payload – i.e., longer messages (Franceschinis et al., 2013). Alert message maximization potentially provides SE Colorado firefighters a clearer picture of the remote grassfire to which they would respond.

The generalizability of the current research's results indicates utility for firefighters providing overwatch to grasslands throughout the world – wherever valuable grasslands intersect with a 4G-LTE on-ramp. Within the United States and outside of SE Colorado, 4G-LTE from multiple carriers exists throughout the Great Plains (nPerf, 2021). U.S. Industries, communities, and ecosystems that rely on the abundance of the Great Plains grasslands abound (USFS, 2021). Therefore, states like Oklahoma, Kansas, Nebraska, Wyoming, Montana, North Dakota, and South Dakota feature use cases ripe for benefit from the present research.

CONCLUSION

The specter of wildfire looms over the SE Colorado grasslands and has wreaked havoc on its communities, industries, flora, and fauna (Grewe, 2020; Lynn & Campbell-Hicks, 2020; Markus, 2022). A review of the literature highlighted research that prescribed rapid alerting at a wildfire's onset – firefighters should receive an alert within six minutes of a fire's detection (Xu et al., 2018). The literature review also revealed the inadequacy of reliance on human-borne fire detection and alerting (Rego & Catry, 2006). To foster greater wildfire alerting speed and assurance, the literature review turned toward previous research and a solution based on network convergence (Crosby & Vafa, 2013; Swain & Ray, 2020).

Network convergence between detective WSNs and the 4G-LTE infrastructure helped to fill a research gap in the literature that existed between fire detection and response entities. WSN wildfire detection solutions exist in mass throughout the literature (Devadevan & Sankaranarayanan, 2017; Kaur & Manshahia, 2017). However, the literature review discovered a deficit of research that dealt with the propagation of a wildfire alert from the detective WSN to firefighters. Therefore, the present research pursued a fire alerting solution that converged the established WSN capabilities with SE Colorado's organic 4G-LTE presence (Atlas Big, 2018; nPerf, 2021) to overcome the wildfire alerting gap.

RECOMMENDATIONS FOR FURTHER RESEARCH

The current effort presented numerous opportunities for additional research. Although the present study identified and addressed a gap in the literature, additional studies could offer more depth and recommend solutions to bolster the alert mechanism between fire detection and response capabilities. The literature is teeming with research that improves the efficacy of fire-detective WSNs (Aksamovic et al., 2017; Devadevan & Sankaranarayanan, 2017; Kaur & Manshahia, 2017). However, the dearth of practice-oriented research that delivers an alert to firefighters in SE Colorado and elsewhere warrants further work on top of the present study.

The current research's incremental construction of delay measurements for COA-A and COA-B encourages the creation of an end-to-end model in network simulators such as NS3 or OMNeT++ (Saluja et al., 2017; Varga & Hornig, 2008). A representative model would capture total transmission delay with a single measurement vice the summation of component metrics. Recreation of COA-B in a different simulation would also confirm the present study's results. Additionally, a network simulation framework like OMNeT++ would allow a more comprehensive representation of wireless channel effects on overall delay (Mallanda et al., 2005).

The creation and testing of a physical COA-B prototype would provide a proof of concept for the current study. 4G-LTE convergence gateways and wireless sensors are readily available to scholar-practitioners for acquisition and configuration (DIGI, 2021; Reese, 2021). Researchers could craft an IEEE 802.15.4-based packet from the last-hop WSN node that carries a pseudo fire detection alert. Performance metrics to the 4G-LTE P-GW or to a firefighting endpoint in SE Colorado would showcase the efficacy of the present work's COA-B solution. More importantly, physical confirmation of WSN and 4G-LTE convergence would bridge the gap between remote grassfire detection and response (Grewe, 2020; Svaldi, 2019).

The present research focused on reducing the delivery delay of a remote grassfire alert to SE Colorado firefighters. However, the study's findings need not apply only to grassfires. Much research and residual challenges exist on the topic of forest fire alerts throughout the world (Devadevan & Sankaranarayanan, 2017; Kadir et al., 2018; Yu et al., 2005). Although the generation mechanisms may differ, propelling an alert over available infrastructure – 4G-LTE or other – offers a workable solution to ensure timely response to unsolicited fires.

Finally, the present study's methodology, design, and method focused on experimentally simulating convergence between WSN and MCN protocols for reduced fire alert delivery delay to SE Colorado firefighters. However, future work could bridge the gap between any varietal of remote sensor network and the audience that consumes sensor data anywhere in the world. Network convergence offers scholar-practitioners the ability to propagate seamless communication across heterogenous networks (Swain & Ray, 2020). Future network convergence research could benefit the availability of alerts from sensor networks that detect every conceivable anomaly at sea, on land, in the air, or even in space.

REFERENCES

Adams, J. T. (2006, March). *An introduction to IEEE STD 802.15.4*. Paper presented at the 2006 IEEE Aerospace Conference. https://doi.org/10.1109/AERO.2006.1655947

Ahmad, A., & Hanzálek, Z. (2018). An energy efficient schedule for IEEE 802.15.4/ZigBee cluster tree WSN with multiple collision domains and period crossing constraint. *IEEE Transactions on Industrial Informatics, 14*(1), 12-23. https://doi.org/10.1109/TII.2017.2725907

Aksamovic, A., Hebibovic, M., & Boskovic, D. (2017, October). *Forest fire early detection system design utilising the WSN simulator*. Paper presented at the 2017 XXVI International Conference on Information, Communication and Automation Technologies (ICAT). https://doi.org/10.1109/ICAT.2017.8171640

Anderson, D. W., & Coleman, D. C. (1985). The dynamics of organic matter in grassland soils. *Journal of Soil and Water Conservation, 40*(2), 211-216. Soil and Water Conservation Society. https://www.jswconline.org/content/40/2/211

Arecchi, F. T., Masserini, G. L., & Schwendimann, P. (1969). Electromagnetic propagation in a resonant medium. *La Rivista Del Nuovo Cimento, 1*(2), 181. https://doi.org/10.1007/BF02887747

Atlas Big. (2018). *Colorado population density by county*. https://www.atlasbig.com/en-us/Colorado-Population-Density

Bengtsson, J., Bullock, J. M., Egoh, B., Everson, C., Everson, T., O'Connor, T., O'Farrell, P. J., Smith, H. G., & Lindborg, R. (2019). Grasslands – More important for ecosystem services than you might think. *Ecosphere*, *10*(2), 1-20. https://doi.org/10.1002/ecs2.2582

Bettany-Saltikov, J., & Whittaker, V. J. (2014). Selecting the most appropriate inferential statistical test for your quantitative research study. *Journal of Clinical Nursing*, *23*(11-12), 1520-1531. https://doi.org/10.1111/jocn.12343

Bhatia, L., Boyle, D., & McCann, J. A. (2018, November). Aerial interactions with wireless sensors. *Proceedings of the 16th ACM Conference on Embedded Networked Sensor System*s, Shenzhen, China. https://doi.org/10.1145/3274783.3275189

Blanca, M. J., Arnau, J., López-Montiel, D., Bono, R., & Bendayan, R. (2013). Skewness and kurtosis in real data samples. *Methodology, 9*(2), 78-84. https://doi.org/10.1027/1614-2241/a000057

Bora, G., Bora, S., Singh, S., & Arsalan, S. M. (2014). OSI reference model: An overview. *International Journal of Computer Trends and Technology (IJCTT)*, *7*(4), 214-218. https://doi.org/10.14445/22312803/IJCTT-V7P151

Borean, C., & Pastrone, C. (2008, June). *GAL: A gateway abstraction layer for fast application development in ZigBee networks*. Paper presented at the 2nd European ZigBee Developers Conference. https://www.researchgate.net/publication/259296970_GAL_a_Gateway_Abstraction_Layer_for_fast_application_development_in_ZigBee_Networks

Brown, M. B., & Forsythe, A. B. (1974). Robust tests for the equality of variances. *Journal of the American Statistical Association*, *69*(346), 364-367. https://doi.org/10.1080/01621459.1974.10482955

Carlier, L., Rotar, I., Vlahova, M., & Vidican, R. (2009). Importance and functions of grasslands. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 37*(1), 25-30. https://notulaebotanicae.ro/index.php/nbha/article/view/3090

CCA. (2021, October 2). *The beef story*. Colorado Cattlemen's Association. https://docs.google.com/document/d/1dKp9b-OBlv1K6uLYNsFotAnVp_bSxY0uVNXUmYgcBNo/edit

Cheney, N. P., & Gould, J. S. (1995). Fire growth in grassland fuels. *International Journal of Wildland Fire, 5*(4), 237-247. https://doi.org/10.1071/WF9950237

Clark, D. (1988, August). The design philosophy of the DARPA internet protocols. *Symposium Proceedings on Communications Architectures and Protocols*, Stanford, California, USA, pp. 106-114. https://doi.org/10.1145/52324.52336

Cox, C. (2012). *An introduction to LTE: LTE, LTE-advanced, SAE and 4G mobile communications.* John Wiley & Sons Ltd. https://dl.acm.org/doi/book/10.5555/2823944

Crosby, G. V., & Vafa, F. (2013, October). *Wireless sensor networks and LTE-A network convergence.* Paper presented at the 38th Annual IEEE Conference on Local Computer Networks. https://doi.org/10.1109/LCN.2013.6761322

CSFS. (n.d.). *Firewise*. Colorado State Forest Service. https://static.colostate.edu/client-files/csfs/pdfs/plains_FW.pdf

CSFS. (2020a). *Colorado plains*. Colorado State Forest Service. https://csfs.colostate.edu/colorado-plains/

CSFS. (2020b). *Wildfire risks on the plains*. Colorado State Forest Service. https://csfs.colostate.edu/colorado-plains/wildfire-risks-on-the-plains/

Cummer, S. A. (2000). Modeling electromagnetic propagation in the Earth-ionosphere waveguide. *IEEE Transactions on Antennas and Propagation, 48*(9), 1420-1429. https://doi.org/10.1109/8.898776

Devadevan, V., & Sankaranarayanan, S. (2017). Forest fire information system using wireless sensor network. *International Journal of Agricultural and Environmental Information Systems (IJAEIS), 3*(8), 52-67. https://doi.org/10.4018/IJAEIS.2017070104

DIGI. (2021, September 6). *4G LTE routers, gateways and modules*. DIGI. https://www.digi.com/products/browse/4g-lte-routers-gateways-modules

DOLA. (2019, May 9). *Colorado: Total population change 2010-2018*. Colorado Department of Local Affairs. https://storage.googleapis.com/maps-static/TtlChg1018.png

Du, X., & Zhao, D. (2009). Polarization modulation of stochastic electromagnetic beams on propagation through the turbulent atmosphere. *Optics Express, 17*(6), 4257-4262. https://doi.org/10.1364/OE.17.004257

Farsi, M., Elhosseini, M. A., Badawy, M., Ali, H. A., & Eldin, H. Z. (2019). Deployment techniques in wireless sensor networks, coverage and connectivity: A survey. *IEEE Access, 7*, 28940-28954. https://doi.org/10.1109/ACCESS.2019.2902072

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175-191. https://doi.org/10.3758/BF03193146

Foster, K. (2013, November 21). *Interpreting results: Absolute difference versus relative difference.* marketingexperiments. https://marketingexperiments.com/digital-analytics/absolute-versus-relative-difference

Franceschinis, M., Pastrone, C., Spirito, M. A., & Borean, C. (2013, October). *On the performance of ZigBee Pro and ZigBee IP in IEEE 802.15.4 networks.* Paper presented at the 2013 IEEE 9th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob). https://doi.org/10.1109/WiMOB.2013.6673344

Georgiades, G., Papageorgiou, X. S., & Loizou, S. G. (2019, April). *Integrated forest monitoring system for early fire detection and assessment.* Paper presented at the 2019 6th International Conference on Control, Decision, and Information Technologies (CoDIT). https://doi.org/10.1109/CoDIT.2019.8820548

Grewe, L. (2020, May 24). *2 grassfires burning in Las Animas County*. KKTV 11 News. https://www.kktv.com/content/news/2-grass-fires-burning-in-Las-Animas-County-570732291.html

Griffiths, M., & Rubright, L. (2018). *Colorado: A geography*. Routledge.

Harris, S. (2013). *CISSP® all-in-one exam guide* (6th ed.). McGraw-Hill Companies.

Hoffman, F. M. (1997). An introduction to Fourier theory. https://warwick.ac.uk/fac/sci/physics/research/cfsa/people/sandrac/lectures/basicfourierintro.pdf

Howitt, I., & Gutierrez, J. A. (2003, March). *IEEE 802.15.4 low rate - Wireless personal area network coexistence issues.* Paper presented at the 2003 IEEE Wireless Communications and Networking, WCNC. https://doi.org/10.1109/WCNC.2003.1200605

Hung, T. C., Tan, P. M., & Thua, H. T. (2015). Application of wireless sensor networks technology for early forest fire warning. *Journal of Selected Areas in Telecommunications (JSAT), 5*(5), 1-6. https://tranconghung.com/File_Upload/Newspaper/71_Cyber%20Journal_Tan_02112015.pdf

Hurt, R. D. (2020, December 13). *Colorado's great plains*. Colorado Encyclopedia. https://coloradoencyclopedia.org/article/colorado%E2%80%99s-great-plains

Ismaili, I. A., Azyat, A., Raissouni, N., Achhab, N. B., Chahboun, A., & Lahraoua, M. (2019, April). *Comparative study of ZigBee and 6LoWPAN protocols.* Paper presented at the Third International Conference on Computing and Wireless Communication Systems, ICCWCS. https://doi.org/10.4108/eai.24-4-2019.2284215

Kadir, E. A., Rosa, S. L., & Yulianti, A. (2018, October). *Application of WSNs for detection land and forest fire in Riau province Indonesia.* Paper presented at the 2018 International Conference on Electrical Engineering and Computer Science (ICECOS). https://doi.org/10.1109/ICECOS.2018.8605197

Kaur, G., & Manshahia, M. S. (2017). Wireless sensor networks for fire detection and control. *International Journal on Future Revolution in Computer Science & Communication Engineering, 3*(12), 14-21. http://www.ijfrcsce.org/index.php/ijfrcsce/article/view/358

Knopik, C. (2020). *A comparative analysis of video-based training and game-based training on information security.* (Publication No. 28030870) [Doctoral dissertation, Colorado Technical University]. ProQuest Dissertations & Theses Global.

Laerd. (2021, August 21). *Dealing with violations of normality*. Laerd Statistics. https://statistics.laerd.com/premium/spss/istt/independent-t-test-in-spss-12.php

LandScope Colorado. (2020). *Shortgrass prairie*. LandScope America. http://www.landscope.org/colorado/ecosystems/featured_ecosystems/iconic_ecosystems/Shortgrass%20Prairie/

LeCain, D. R., Morgan, J. A., Schuman, G. E., Reeder, J. D., & Hart, R. H. (2002). Carbon exchange and species composition of grazed pastures and exclosures in the shortgrass steppe of Colorado. *Agriculture, Ecosystems & Environment*, *93*(1-3), 421-435. https://doi.org/10.1016/S0167-8809(01)00290-0

Lee, H., Cerpa, A., & Levis, P. (2007, April). Improving wireless simulation through noise modeling. *Proceedings of the 6th international conference on Information processing in sensor networks*, Cambridge, Massachusetts, USA. https://doi.org/10.1145/1236360.1236364

Li, P., Li, J., Nie, L., & Wang, B. (2010, March). *Research and application of ZigBee protocol stack*. Paper presented at the 2010 International Conference on Measuring Technology and Mechatronics Automation. https://doi.org/10.1109/ICMTMA.2010.275

Luaenroth, W. K., Burke, I. C., & Gutmann, M. P. (1999). The structure and function of ecosystems in the central North American grassland region. *Great Plains Research, 9*(2), 223-259. https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1452&context=greatplainsresearch

Lynn, N., & Campbell-Hicks, J. (2020, April 12). *Crews respond to 'massive' wildfire in southeastern Colorado.* 9News. https://www.9news.com/article/news/local/wildfire/crews-respond-to-massive-wildfire-in-southeastern-colorado/73-f9c2a9a8-7c7e-4102-bd0f-769f9f35bfbf

Mallanda, C., Suri, A., Kunchakarra, V., Iyengar, S. S., Kannan, R., Durresi, A., & Sastry, S. (2005, January 24). *Simulating wireless sensor networks with OMNeT++*. https://users.cis.fiu.edu/~iyengar/publication/backup/J-(2005)%20-%20Simulating%20Wireless%20Sensor%20Networks%20with%20OMNeT-%20%5BACM%5D.pdf

Markus, B. (2022, January 5). *Boulder Country firefighters lost crucial early minutes because they couldn't find the start of the Marshall fire*. CPR News. https://www.cpr.org/2022/01/05/boulder-county-marshall-fire-timeline/

Mills, M., van de Bunt, G. G., & de Bruijn, J. (2006). Comparative research: Persistent problems and promising solutions. *International Sociology, 21*(5). https://doi.org/10.1177/0268580906067833

NIST. (2021, February 17). *Availability*. CSRC. https://csrc.nist.gov/glossary/term/availability

nPerf. (2021, August 21). *3G / 4G / 5G in Pueblo coverage map, United States.* https://www.nperf.com/en/map/US/5435464.Pueblo/-/signal/

Osborn, W. R., & Bennett, J. W. (2012). *ZigBee/IP gateway* (U.S. Patent No. 8,149,849). U.S. Patent and Trademark Office. https://patents.google.com/patent/US8149849B2/en

Osborne, J. B. (2020). *Quantitative evaluation of the performance impact of type-I virtualization on a NewSQL relational database management system.* (Publication No. 28029312) [Doctoral dissertation, Colorado Technical University]. ProQuest Dissertations & Theses Global.

Osorio, O. A. G., Dazai, B. S. R., & Salcedo, O. J. (2016, January). *Comparative study of performance for 804.15.4 ZigBee and 6LoWPAN protocols.* Paper presented at the 42nd International Conference on Current Trends in Theory and Practice of Computer Science (SOFSEM 2016). http://ceur-ws.org/Vol-1548/059-Osorio.pdf

Ostinato. (2020, November 22). *Ostinato: Traffic generator for network engineers.* https://ostinato.org/

Patil, B. R., Moharir, M., Mohanty, P. K., Shobha, G., & Sajeev, S. (2017, December). *Ostinato - A powerful traffic generator.* Paper presented at the 2017 2nd International Conference on Computational Systems and Information Technology for Sustainable Solution (CSITSS). https://doi.org/10.1109/CSITSS.2017.8447596

Qadir, S., & Quadri, S. M. K. (2016). Information availability: An insight into the most important attribute of information security. *Journal of Information Security, 7*(3), 185-194. https://doi.org/10.4236/jis.2016.73014

Reese, L. (2021, September 6). *Industrial wireless sensor networks*. Mouser Electronics. https://www.mouser.com/applications/rf-sensor-networks/

Rego, F. C., & Catry, F. X. (2006). Modelling the effects of distance on the probability of fire detection from lookouts. *International Journal of Wildland Fire, 15*(2), 197-202. https://doi.org/10.1071/WF04016

Rico, D., & Merino, P. (2020). A survey of end-to-end solutions for reliable low-latency communications in 5G networks. *IEEE Access, 8*, 192808-192834. https://doi.org/10.1109/ACCESS.2020.3032726

Salkind, N. J. (2012). *Exploring research*. Pearson.

Saluja, A. K., Dargad, S. A., & Mistry, K. (2017). A detailed analogy of network simulators – NS1, NS2, NS3, and NS4. *International Journal on Future Revolution in Computer Science & Communication Engineering, 3*(12), 291-295. http://www.ijfrcsce.org/index.php/ijfrcsce/article/view/411

Sekaran, U., & Bougie, R. (2013). *Research methods for business: A skill-building approach* (6th ed.). John Wiley & Sons Ltd.

Shan, L., Fang, W., Qiu, Y., He, W., & Sun, Y. (2016). Smart mobile gateway: Technical challenges for converged wireless sensor networks and mobile cellular networks. *International Journal of Future Generation Communication and Network, 9*(9), 87-98. https://doi.org/10.14257/ijfgcn.2016.9.9.08

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika*, *52*(3/4), 591-611. https://doi.org/10.2307/2333709

Silicon Labs. (n.d.). *AN1138: Zigbee mesh network performance*. Silicon Labs. https://www.silabs.com/documents/login/application-notes/an1138-zigbee-mesh-network-performance.pdf

Smith, D. R., & Schurig, D. (2003). Electromagnetic wave propagation in media with indefinite permittivity and permeability tensors. *Physical Review Letters, 90*(7), 077405. https://doi.org/10.1103/PhysRevLett.90.077405

Soijoyo, S., & Ashari, A. (2017). Analysis of ZigBee data transmission on wireless sensor network topology. *International Journal of Advanced Computer Science and Applications (IJACSA), 8*(9), 145-151. https://pdfs.semanticscholar.org/63cc/46240e66258dc35ede6699a4677616b8cc04.pdf

Stein, V. (2018, March 6). *What is the speed of light?* Space.com. https://www.space.com/15830-light-speed.html

Svaldi, A. (2019, December 29). 5G technology could widen the digital divide in rural Colorado. *The Denver Post*. https://www.denverpost.com/2019/12/29/5g-technology-divide-rural-colorado/

Swain, A., & Ray, A. K. (2020). A survey on WSN and MCN convergence networks. *Journal of Telecommunications & Information Technology, 2020*(1), 39-49. https://doi.org/10.26636/jtit.2020.137619

Swain, A., Ray, A. K., & Swain, P. K. (2016, October). *Modeling and analysis of data flow in MAC layer of WSN-MCN convergence network*. Paper presented at the 2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES). https://doi.org/10.1109/SCOPES.2016.7955693

Swain, A., Ray, A. K., & Swain, P. K. (2018, July). *Reservation based resource allocation with dynamic admission probability for WSN-MCN convergence network*. Paper presented at the 2018 International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering (ICRIEECE). https://doi.org/10.1109/ICRIEECE44171.2018.9009242

Thompson, C. B. (2009). Descriptive data analysis. *Air Medical Journal, 28*(2), 56-59. https://doi.org/10.1016/j.amj.2008.12.001

Tomić, I., & McCann, J. A. (2017). A survey of potential security issues in existing wireless sensor network protocols. *IEEE Internet of Things Journal, 4*(6), 1910-1923. https://doi.org/10.1109/JIOT.2017.2749883

Tudor, A. (2014). *A study of open-source relational database performance in virtual computing environments.* (Publication No. 3579395) [Doctoral dissertation, Northcentral University]. ProQuest Dissertations & Theses Global.

Tutorialspoint. (2020, November 19). *LTE protocol stack layers*. https://www.tutorialspoint.com/lte/lte_protocol_stack_layers.htm

USFS. (2021, August 31). *The national grasslands story*. U.S. Forest Service. https://www.fs.fed.us/grasslands/aboutus/index.shtml

Varga, A., & Hornig, R. (2008, March). *An overview of the OMNeT++ simulation environment. Proceedings of the 1st International Conference on Simulation Tools and Techniques for Communications, Networks and Systems & Workshops*, Marseille, France. https://dl.acm.org/doi/10.5555/1416222.1416290

Varghese, J. M., Nibi, K. V., Varghese, V. T., & Rao, S. (2015). A survey of the state of the art in Zigbee. *International Journal on Cybernetics & Informatics (IJCI)*, *4*(2), 145-155. https://doi.org/10.5121/ijci.2015.4214

Wagoner, M. P. (2021). *Examining the relationship between converged-network architecture and remote grassfire alert transmission delay in southeast Colorado.* (Publication No. 28772828) [Doctoral dissertation, Colorado Technical University]. ProQuest Dissertations & Theses Global.

Wang, M. H., Chen, L. W., Chi, P. W., & Lei, C. L. (2017). SDUDP: A reliable UDP-based transmission protocol over SDN. *IEEE Access*, *5*, 5904-5916. https://doi.org/10.1109/ACCESS.2017.2693376

Wang, Y. (2021). Connecting the parts with the whole: Toward an information ecology theory of digital innovation ecosystems. *MIS Quarterly, 45*(1b), 397-422. https://doi.org/10.25300/MISQ/2021/15864

Wireshark. (2021, May 11). *Wireshark*. https://www.wireshark.org/

Xia, J., Yun, R., Yu, K., Yin, F., Wang, H., & Bu, Z. (2012, September). *Coordinated multimode (cellular - WSN) user equipment accessing wireless sensor network mechanism.* Paper presented at the 2012 Fourth International Conference on Intelligent Networking and Collaborative Systems. https://doi.org/10.1109/iNCoS.2012.19

Xu, Y.-H., Sun, Q.-Y., & Xiao, Y.-T. (2018). An environmentally aware scheme of wireless sensor networks for forest fire monitoring and detection. *Future Internet, 10*(10), 102. https://doi.org/10.3390/fi10100102

Yang, T., Bayram, Y., & Volakis, J. L. (2010). Hybrid analysis of electromagnetic interference effects on microwave active circuits within cavity enclosures. *IEEE Transactions on Electromagnetic Compatibility, 52*(3), 745-748. https://doi.org/10.1109/TEMC.2009.2038993

Yu, L., Wang, N., & Meng, X. (2005, September). *Real-time forest fire detection with wireless sensor networks*. Paper presented at the 2005 International Conference on Wireless Communications, Networking and Mobile Computing. IEEE. https://doi.org/10.1109/WCNM.2005.1544272

Zhang, J., Shan, L., Hu, H., & Yang, Y. (2012). Mobile cellular networks and wireless sensor networks: Toward convergence. *IEEE Communications Magazine, 50*(3), 164-169. https://doi.org/10.1109/MCOM.2012.6163597

Zhao, L., Wang, H., & Zhong, X. (2019). Interference-aware channel assignment algorithm in D2D overlaying cellular networks. *KSII Transactions on Internet and Information Systems (TIIS), 13*(4), 1884-1903. https://doi.org/10.3837/tiis.2019.04.008

ZigBee. (2015, August 5). *ZigBee specification*. https://zigbeealliance.org/wp-content/uploads/2019/11/docs-05-3474-21-0csg-zigbee-specification.pdf

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