ČESKÁ ZEMĚDĚLSKÁ UNIVERZITA V PRAZE

PROVOZNĚ EKONOMICKÁ FAKULTA

Metody sběru, zpracování a vizualizace IoT dat v prostředí GIS

disertační práce

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Abstrakt:

Práce je zaměřena na výzkum v nové oblasti nazývané IoT (Internet of Things) ve spojení s Geografickým informačním systémem (GIS). Nový vědní obor IoT odráží aktuální vědecké a technologické poznatky umožňující inovativní přístupy zejména v oblasti přenosu dat i jejich získávání. V oblasti GIS se práce věnuje novým možnostem a nástrojům pro zpracování IoT datových toků. Práce formou souboru čtyř publikací popisuje metody a doporučení pro různé optimalizace provozu IoT sítí senzorů v kontextu Geografických informačních systémů. Lze tak řešit technická či ekonomická omezení znemožňující uplatnění těchto nových systémů v praxi, a to zaměřením se na zajištění dostatku elektrické energie pro spolehlivý a dlouhodobý chod bateriových zařízení. Detailněji je prezentována možnost využití Fuzzy logiky k interpretaci informace samotným senzorem. Dále jsou představeny výstupy z experimentálního měření parametrů bezdrátového přenosu technologií LoRaWAN, jakožto zástupce z oblasti low-power wide-area network (LPWAN), a to vše ve vztahu k prostředí GIS. Konkrétně se jedná o sběr a přenos informace senzorickým IoT zařízením, zajištění geografické polohy a následnou vizualizaci získaných informací v prostředí GIS.

Klíčová slova:

Senzory, LPWAN, GIS, IoT, Big Data, bateriová zařízení, Fuzzy systém

Abstract:

The work is focused on research in a new area called IoT (Internet of Things) in connection with the Geographical Information System (GIS). The new scientific field of IoT reflects current scientific and technological knowledge enabling innovative approaches, especially in the field of data transmission and data acquisition. In the field of GIS, the work is devoted to new possibilities and tools for processing IoT data flows. The work in the form of a set of four publications describes methods and recommendations for various optimizations of the operation of IoT sensor networks in the context of Geographical Information Systems. In this way, technical or economic limitations preventing the application of these new systems in practice can be solved, by focusing on ensuring sufficient electrical energy for the reliable and long-term operation of battery devices. The possibility of using Fuzzy logic to interpret information by the sensor itself is presented in more detail. Furthermore, the outputs from the experimental measurement of the parameters of wireless transmission by LoRaWAN technology are presented, as a representative from the field of low-power wide-area network (LPWAN), and all this in relation to the GIS environment. Specifically, it involves the collection and transmission of information by sensory IoT devices, ensuring geographic location and subsequent visualization of the obtained information in a GIS environment.

Keywords:

Senzors, LPWAN, GIS, IoT, Big Data, battery devices, Fuzzy system

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1 Úvod

Klíčem k řešení většiny problémů je dostatek relevantních informací popisujících daný problém. Mezi významné problémy současnosti lze zahrnout i vliv prostředí na fungování lidské společnosti. Vážným a dlouhodobým problémem České republiky je mimo jiné hledání ideálního způsobu hospodaření s vodou. Průměrné roční srážky se významně nemění, dochází však ke změnám v jejich rozložení během roku. Změny vodního režimu krajiny také úzce souvisí s proměnami uspořádání krajiny jako jsou výstavba liniových prvků dopravní infrastruktury, rozšiřování zástavby, devastace rozsáhlých ploch území v těžebních oblastech, intenzifikace zemědělského hospodaření, odvodňování a provádění meliorací, scelování a rozorávání pozemků, zhoršení půdní struktury zemědělské půdy, změna skladby lesa, aplikace výhradně technických přístupů při regulaci vodních toků a řešení protipovodňové ochrany urbanizovaných území. A právě v těchto oblastech lze využít technologického pokroku v oblasti senzoriky a zpracování dat. (Rieder, 2015; komise VODA-SUCHO, 2017)

Za posledních 5 let vzniklo mnoho technologií, které přináší nové možnosti. Zejména se jedná o nízkoenergetickou bezdrátovou komunikaci, nízkoenergetickou senzoriku a nové metody pro zpracování, vyhodnocení a vizualizaci dat. Nabízí se tak příležitost efektivně využít tyto technologie nejen při hospodaření s vodou. Skutečným problémem je absence metodologie, díky které by bylo možné tyto technologie efektivně a komplexně využít pro konkrétní řešení. Největším přínosem komplexních přístupů by mohla být významná ekonomická úspora při nasazování těchto „smart solution“, a to díky snížení nákladů spojených zejména s jejich provozem. Například pro získávání informací lze využít velmi přesné senzory, které mohou být napájené bateriemi, což zjednodušuje jejich instalaci do požadovaných míst. Optimalizací provozních režimů zařízení a vzájemnou spoluprací jejich senzorů lze mimo jiné výrazně prodloužit životnost baterie, čímž se sníží počet servisních zásahů nutných pro jejich výměnu.

Optimalizace na poli technologického řešení tak v celkovém důsledku zlevňují cenu dat, respektive informací z nich získaných. Vhodně interpretované informace pak napomáhají lepšímu pochopení nejen hydrologických systémů a usnadňují společnosti činit odpovědná rozhodnutí napříč mnoha odvětvími.

2 Výzkumná mezera – Cíle práce

Na základě syntézy vybraných literárních zdrojů zabývajících se problematikou internetu věcí v kontextu sběru časoprostorových senzorických dat, bylo identifikováno několik specializovaných oblastí. Konkrétně jsou to oblasti sběru dat, jejich zpracování (přenos, uložení, agregace, normalizace, validace atd.) a vizualizace. V těchto oblastech byly identifikovány výzkumné mezery, z nichž byly zvoleny takové, u kterých lze předpokládat, že pozitivní výzkumný výsledek může přinést novou metodu poskytující přidanou hodnotu současným řešením. Práce se nezabývá kybernetickým zabezpečením, které je však nutné zohlednit při případném praktickém využití.

Na následujícím přehledovém diagramu 1 jsou znázorněny vztahy jednotlivých komponent.

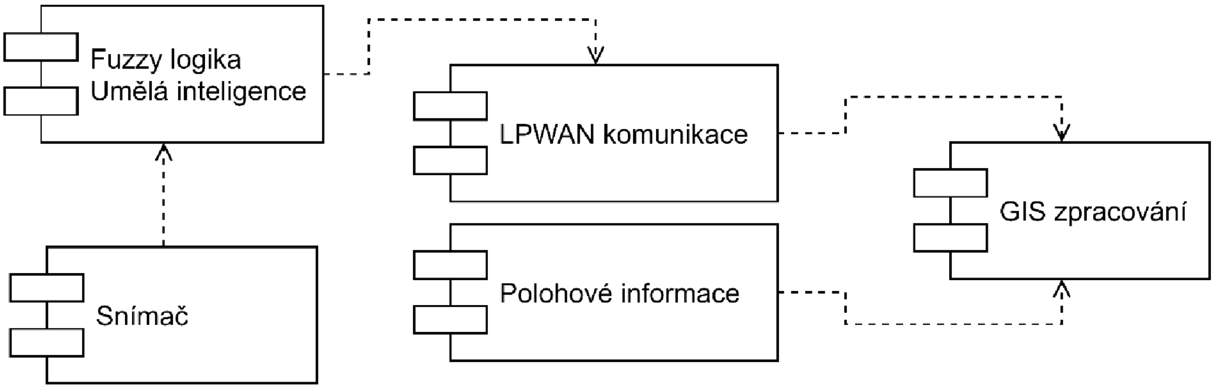


Diagram 1: Přehledový diagram vztahu jednotlivých komponent

První oblastí zvolenou jako dílčí cíl práce je ověření hypotézy o využití matematických funkcí zejména podoboru Fuzzy logiky k agregaci informace samotným senzorem a tím snížení datového obejmu přenášených dat. Omezení objemu přenášených dat má za následek pokles energetické náročnosti zařízení, čímž se prodlužuje jeho životnost na baterii, případně mu umožňuje komunikovat častěji.

Druhou oblastí je výzkum samotného radiového přenosu dat v reálném prostředí. Bylo identifikováno, že ve spektru komunikačních technologií, které patří do kategorie LPWAN, jsou publikovány výsledky hodnotící například použitelnost konkrétních technologií v určitých aplikacích a prostředích. Dále jsou technologie vzájemně porovnávány a případně jsou hodnoceny limity technologií v krajních mezích použitelnosti. Byl tedy stanoven cíl provést experimentální měření standartního komunikačního přenosu a analyzovat případné anomálie upozorňující na vlivy s dopadem na bezdrátový přenos dat.

Třetí oblast souvisí s metodami získávání polohové informace samotnými senzorickými zařízeními, aplikačním zpracováním a vizualizací dat, která tuto polohovou informaci obsahují. Obecně pro zpracování a vizualizaci prostorových dat slouží GIS, kterému je věnováno mnoho publikací zejména se zaměřením na principy geoinformatiky, geografie, kartografie atd. Pro tuto práci tak byl stanoven cíl ověřit možnosti využití geografického informačního systému pro senzorická data přicházející v reálném čase za účelem jejich poskytnutí ve formě vhodné grafické prezentace a zhodnotit možnosti využití nástroje GIS jako systému pro podporu rozhodování. Například získávání informací z rozsáhlých území, která však tvoří jeden systém. Typově se může jednat o říční systém, u kterého lze při znalosti říčního profilu a poloze jednotlivých senzorů minimalizovat aktivní dobu používání jednotlivých zařízení, díky dynamické změně chování na základě překročení prahové hodnoty jiným zařízením výše po toku řeky.

Hlavním cílem této práce je tedy navrhnout metody a doporučení optimalizující provoz IoT sítí senzorů pro potřeby geografických informačních systémů. Řešit tak technická či ekonomická omezení znemožňující uplatnění těchto nových systémů v praxi, zejména pak se zaměřením na zajištění dostatku elektrické energie pro spolehlivý a dlouhodobý chod zařízení.

Dále pak dlouhodobé návazné výzkumy mohou být zaměřeny na automatizovanou spolupráci jednotlivých zařízení fungujících v rámci jednoho systému. A to zejména s ohledem na predikce trendů snímaných veličin, při kvalifikaci jejich důležitosti a v kontextu jejich vzájemné i absolutní polohy.

3 Metodická poznámka

V této části je představen teoreticko-metodologický rámec.

K dosažení cílů bylo využito jak obecně teoretických, tak i empirických výzkumných metod. Obecně teoretické metody byly uplatněny zejména ve fázi poznávání vědeckého problému a při jeho detailním zkoumání. Analýza byla využita pro rozložení celé problematiky na nižší entity. Speciálním případem analýzy, související s touto prací, je systémová analýza z oblasti obecné teorie systémů. V další částech na analýzu navazuje syntéza, díky které je vytvořen nový vědecký obraz zkoumaných jevů. Z povahy různorodosti studovaných technologií byla také využívána komparace, tedy vyhledávání shod a odlišností u porovnávaných entit. Literatura zabývající se komparací ukazuje na různé přístupy k vymezení komparace. V oblasti technologií lze velmi efektivně využít i metody generalizace (zobecnění). Tato metoda vychází z předpokladu, že určitou vlastnost (vlastnosti) zkoumaných předmětů lze zobecněním přisoudit i dalším předmětům patřícím do stejné množiny, aniž by bylo nutné zbývající předměty podrobovat detailnímu zkoumání. Zejména pro popisnou část bylo využito metod modelování. Model je zjednodušujícím zobrazením určité reality a může mít různou formu. Tomu také odpovídají různé druhy modelů. Model vychází z existence reality, u jejíž složitosti usiluje o zjednodušení formou příslušného ideálního či materiálního zobrazení.(Ochrana, 2019)

Empirické výzkumné metody jsou třída metod, která se opírá o empiricky orientovanou metodologii vědy. Obecně je pro empirické metody charakteristické, že jsou založeny na zkušenostních postupech, kdy daný empirický postup může být realizován přímo zkoumajícím subjektem nebo je uskutečňován prostřednictvím přístrojů (např. měřením). Dále je také využito pozorování, tedy empirická metoda, která prostřednictvím smyslového nazírání získává informace o zkoumaném předmětu. Jde o výběrové vnímání, což znamená, že při použití této metody jsou vyčleňovány ze zkoumaného předmětu ty jeho části, které jsou sledovány. Z objektu je tak vymezována jeho určitá část (podsystém) – tedy předmět zkoumání. Na výzkumný předmět se zaměřují výzkumné cíle. Zkoumaný předmět je mentálně vymezován (izolován) od ostatních předmětů tak, aby byly eliminovány všechny faktory, které by rušily zkoumání. Jestliže je zkoumaný jev patřičně izolován od rušivých faktorů, je možné jej pozorovat a provádět jeho analýzu s ohledem na stanovené výzkumné cíle. (Ochrana, 2019)

3.1 Rámcový metodický postup

Práce byla realizována za využití následujícího rámcového metodického postupu, který byl schválen v rámci obhajoby metodické části před samotnou realizací činností.

- Formulace pracovní hypotézy výzkumu.
- Vymezení pojmů a stavu současného poznání (analýza stavu zkoumané oblasti a literárních zdrojů, komparace dostupných technologií, syntéza a formulace získaných poznatků).
- Vytvoření sítě partnerů pro výzkum, a to jak z prostředí ČZU, tak externích. Partneři jsou vybíráni v následující oblastech:
    - aplikační partner neboli koncový zákazník případného řešení,
    - technologičtí dodavatelé (HW, konektivita, výpočetní výkon),
    - oboroví specialisté (GIS, AI, IoT, Fuzzy logic, BigData).
- Provedení systémové analýzy prvků a vazeb se zaměřením na metody neural network a fuzzy systems, dále na technologie Low-power WAN přenosu dat, (LoRaWAN, Sigfox, LTE-NB, BLE) s využitím obecně teoretické metody modelování a znázornění prostřednictvím modelovacích nástrojů.
- Empirické ověření pracovních hypotéz zejména za využití zařízení komunikujících na bezdrátových sítích WiFi, LoRaWAN, atd. a Geografického informačního systému včetně mapových vrstev (Arc500, DMR 5G, Ortofoto atd.). Vše za podpory vědeckých laboratoří PEF.
- Provedení měření na experimentálních zařízeních v různých prostředích, pořízení dat a metadat z provozu jednotlivých technologií a jejich zpracování za využít IoT prostorové analýzy.
- Provedení syntézy získaných poznatků a jejich prezentace formou vědeckých publikací a konferencí.
- Formulace konkrétních a generalizovaných doporučení pro implementaci IoT technologií.
- Vyhodnocení úspěšnosti dosažených výsledků a jejich případná generalizace.

4 Literární přehled – současný stav výzkumu

Rychlý vývoj hardwaru, softwaru a komunikačních technologií v posledním desetiletí usnadnil rozšíření senzorů, aktuátorů a heterogenních zařízení připojených přes internet (označovaných jako internet věcí, stručně IoT). Tato zařízení shromažďují a vyměňují obrovská množství dat a nabízí novou třídu pokročilých služeb, které se vyznačují dostupností kdekoli, kdykoli a komukoli. Nicméně bez inteligence mohou systémy IoT a obecně senzorové sítě fungovat pouze jako běžné informační systémy založené na předem definovaných pravidlech. Speciálním případem informačních systémů je Geografický informační systém, který rozšiřuje data o polohovou složku a je tak možné z dat lépe interpretovat širší souvislosti, případně vytvářet digitální dvojčata. Dále přidání umělé inteligence (AI) do mixu může umožnit poskytování služeb podle zvyklostí, aktivit a reálných kontextů uživatelů. Kombinace GIS a AI s internetem věcí otevírá svět neomezenému technologickému potenciálu. (Choi et al., 2020)

4.1 Senzory a HW

Aktuálnost tématu znázorňuje například speciální sekce časopisu Sensor Networks obsahující recenzované články související s nejnovějším výzkumem a vývojem v oblasti senzorových sítí. Jedná se o interdisciplinární doménu, která se skládá z bezdrátové a drátové komunikace, algoritmů a protokolů a také zdrojů energie pro zásobování těchto sítí. Tato část se zabývá teoretickými a experimentálními problémy, zejména s ohledem na vzestup aplikací internetu věcí (IoT), které umožňují chytré připojení několika zařízení. Obecně si tato sekce klade za cíl poskytnout badatelům platformu pro publikování jejich vědecké práce, která může ovlivnit vědeckou komunitu i širokou veřejnost.(Sensor Networks – A section of Sensors)

Pokrok v oblasti Micro-Electro-Mechanical-Systems (MEMS), technologie mikrokontrolérů a myšlenka internetu věcí motivuje vývoj bezdrátových modulů (např. WiFi, Bluetooth, Zigbee a LoRa), které jsou malé a cenově dostupné. (Azmi et al., 2018b)

4.2 Sítě a jejich algoritmy a technologie

V oblasti podnikových LAN (Local Area Network) sítí je aktuální téma Software Defined Networking (SDN), tedy koncept, v rámci kterého jsou jednotlivé aktivní síťové prvky konfigurovány jako jeden celek, a to automaticky nebo ručním zásahem administrátora. Tento přístup také přináší nové možnosti získávání provozních informací z jednotlivých aktivních prvků, což je využitelné například pro lokalizaci wifi klientů. Tato síťová rekonfigurace v oblasti LPWAN sítí zatím není rozšířená. A to zejména z důvodu, že na koncová zařízení jsou kladeny další požadavky, jako je například požadavek na nízkou spotřebu při bateriovém provozu. Dále neexistují povinné standardy pro výrobce LPWAN zařízení a portfolio komunikačních technologií je tak velmi široké, ovšem většinou bez vzájemné kompatibility. (Shafique et al., 2020; Li et al., 2020; Papan et al., 2020; Guo et al., 2019)

Ve snaze poskytnout interoperabilitu a podporu Ipv6 pro IoT zařízení, a tím propojit svět klasického IT a IoT, navrhla Internet Engineering Task Force (IETF) zásobník 6LoWPAN. Zde bylo opět potvrzeno, že zvláštnosti a hardwarová omezení sítí spojených se zařízeními IoT vedou k několika výzvám, zejména u směrovacích protokolů. IETF ve svém návrhu zásobníku standardizuje RPL (Ipv6 Routing Protocol for Low-Power and Lossy Networks) jako směrovací protokol pro Low-power and Lossy Networks (LLN). Tato technologie se příliš nerozšířila, ale lze očekávat potenciál v oblasti IEEE 802.11ah, umožňující provoz bezdrátových sítí IEEE 802.11 ve frekvenčních pásmech pod 1 GHz s dosahem přenosu do 1 km a minimální datovou rychlostí 100 Kb/s. (Sobral et al., 2019; Society, 2017)

Nejperspektivnější technologií v oblasti LPWAN se zdá být technologie LoRaWAN, které se také věnuje mnoho autorů a má již široké uplatnění v praxi. LoRaWAN je zcela novou technologií, která definuje kompletní komunikační model. Zejména specifická je fyzická a síťová vrstva, které jsou navrženy k přenosu malého objemu dat na velké vzdálenosti s minimálním energetickým výdajem. Obdobných vlastností dosahují také technologie NB-IoT, LTE Cat M1 případně Sigfox. Největší předností technologie LoRaWAN pro akademický výzkum je otevřenost technologie, tedy možnost budovat vlastní sítě a v nich provozovat koncová zařízení bez porušení licenčních a jiných podmínek. (Farhad et al., 2020; Semtech, 2020; Azmi et al., 2018a; Augustin et al., 2016)

4.3 Umělá inteligence a IoT

Umělá inteligence (AI) a její podoblast hlubokého učení v posledních letech přitáhly pozornost mnoha výzkumníků. Pokroky v technologiích zároveň umožňují generování nebo shromažďování velkého množství cenných dat (např. dat ze senzorů) z různých zdrojů v různých aplikacích, jako jsou ty pro internet věcí (IoT), které se zaměřují na rozvoj chytrých měst. Vzhledem k dostupnosti senzorických dat z různých zdrojů je pro efektivní integraci velkých dat vyžadována fúze informací ze senzorů.(Leung et al., 2019; Saheb and Izadi, 2019; Stočes et al., 2018)

Data science nebo „data-drive research“ je výzkumný přístup, který využívá reálná data k získání náhledu na chování systémů. Umožňuje analýzu malých, jednoduchých i velkých a složitějších systémů za účelem posouzení, zda fungují podle zamýšleného návrhu a případných modelových simulací. (Kulin et al., 2016)

Velmi inspirativní prací je využití fuzzy logiky pro směrování v bezdrátových senzorových sítích. Algoritmy jsou široce používány kvůli jejich vysoké energetické účinnosti a škálovatelnosti. Ve schématech shlukování jsou uzly organizovány ve formě shluků a každý shluk je řízen hlavou shluku. Jakmile jsou hlavy clusteru vybrány, vytvoří páteřní síť pro periodické shromažďování, agregaci a předávání dat do základnové stanice pomocí směrování s minimální energií (náklady). Tento přístup výrazně prodlužuje životnost sítě.(Razzaq and Shin, 2019; Qaiyum et al., 2020) Praktickým příkladem může být Hierarchical Agglomerative Clustering of Bicycle Sharing Stations Based on Ultra-Light Edge Computing. (Díaz et al., 2020)

Velmi aktivní výzkum uplatnění metod fuzzy systémů probíhá v úzké oblasti smart mobility. Autonomní vozidla fungují v dopravních scénářích v reálném čase. Profesionální řidiči obvykle řídí instinktivní prostředky, které jim umožňují téměř optimálně dosáhnout svého cíle, a přitom dodržovat všechny dopravní předpisy. Reaktivní plánování je proto velmi důležité pro dopravní scénáře. Kapitola zkoumá použití reaktivní metodologie, konkrétně fuzzy logiky, pro navigaci vozidla. Plánovač je generován pomocí evolučního algoritmu, který se podobá fázi učení profesionálních řidičů. Také proniká například do oblasti Smart home (Kala, 2016; Patel and Champaneria, 2017; Ross, 2004)

4.4 Lokalizace v rámci IoT pro aplikace GIS

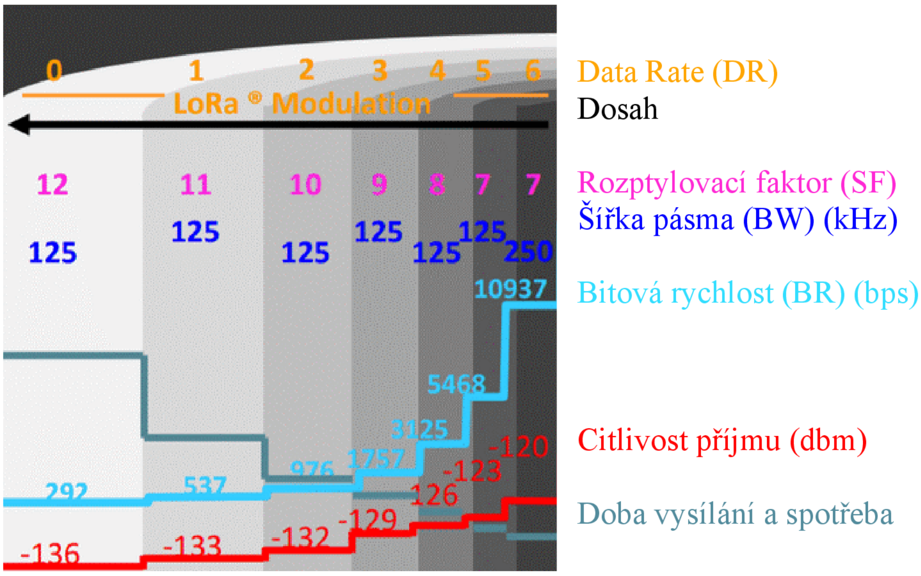
Bezdrátové senzorové sítě se stávají všudypřítomnými a jejich aplikační oblasti se každým dnem rozšiřují. Lokalizační algoritmy hrají důležitou roli při zvyšování užitečnosti shromážděných dat tím, že umožňují senzorům určit místo, ze kterého je každý datový paket získáván. Lokalizaci lze provést implementací algoritmů založených na majáku nebo algoritmů založených na signaturách. Velká část výzkumných prací v této oblasti předpokládá indikátor síly přijímaného signálu (RSSI) jako parametr v jejich lokalizačních algoritmech. Vzhledem k tomu, že RSSI je klíčovým parametrem, byly provedeny praktické experimenty pro posouzení, zda by RSSI skutečně mohly být použity lokalizačními algoritmy k určení vzdáleností mezi senzory.(Parameswaran et al., 2009; Sadowski and Spachos, 2018)

Existují však i jiné metody lokalizace, založené na principu přesného měření času.

LoRaWAN se dobře hodí pro podporu aplikací internetu věcí (IoT). Umožňují omezeným zařízením (uzlům) připojení ke cloudu na velké vzdálenosti a s nízkou spotřebou energie.

Veřejné sítě LoRaWAN jsou nasazovány s funkcí geolokace uzlů pomocí stejné techniky časového rozdílu doručených zpráv (TdoA) jako je použita u GPS. Přestože GPS poskytuje přesné aktualizace polohy v reálném čase, má nevýhodu v tom, že spotřebovává značné množství energie na mobilním zařízení, protože měření TdoA musí být zpracováno lokálně. V důsledku toho je nutná pravidelná výměna baterie nebo její nabíjení. S LoRa probíhá zpracování TdoA na úrovni sítě, což umožňuje zařízením fungovat roky bez výměny baterie. Pokud je 250mAh baterie vybitá po 1000 výpočtech GPS, je možné minimálně 20000 přenosů LoRa při použití stejné baterie.(Aernouts et al., 2020; Podevijn et al., 2018; Fargas and Petersen, 2017; Chen et al., 2020) Velmi relevantní prací je také práce Matrix Completion Optimization for Localization in Wireless Sensor Networks for Intelligent IoT. (Nguyen and Shin, 2016)

Samotná spotřeba, při komunikaci zařízení využívající LoRa modulaci, je závislá na nastavení parametrů modulace. Kde nejnižší DR (Data Rate) poskytuje maximální dosah, ale významně roste spotřeba. Naopak při nastavení DR na hodnotu 6 je možné přenášet data vyšší přenosovou rychlostí při spotřebování významně menšího množství energie. Detailněji je toto uvedeno na následujícím obrázku 1.



Obrázek 1: Parametry LoRa modulace, zdroj: https://lora-alliance.org/

Relevantnost a důležitost využití metodologie prostorové analýzy popisuje Christopher Cappelli, Esri. „Když jsem více než 25 let sledoval růst odvětví GIS, viděl jsem inovace v problémech, které řešíme, v lidech, které můžeme oslovit pomocí technologie, v příbězích, které vyprávíme, a v rozhodnutích, která pomáhají našim organizacím a celému světu k větší úspěšnosti. Co se však nezměnilo, je náš dlouhodobý cíl lépe porozumět našemu světu pomocí prostorové analýzy. Na cestách po světě jsem se setkal s lidmi z mnoha různých kultur, kteří pracují v celé řadě průmyslových odvětví. Když však naslouchám jejich poslání a výzvám, existuje společný vzorec: všichni mluvíme stejným jazykem – je to jazyk prostorové analýzy. Tento jazyk se skládá ze základní sady otázek, které si klademe, taxonomie, která organizuje a rozšiřuje naše chápání, a základních kroků k prostorové analýze, které ztělesňují, jak řešíme prostorové problémy. Doporučuji každému z vás, aby se naučil a sdělil světu sílu prostorové analýzy. Naučte se definici, naučte se slovní zásobu a postup, a co je nejdůležitější, umět mluvit tímto jazykem do světa. Největší potenciál pro změnu a úspěch nastane, když všichni rozumíme a mluvíme stejným jazykem – jazykem prostorové analýzy“. (ESRI, 2011)

5 Výsledky

Výsledky odpovídající stanoveným cílům autor publikoval v rámci své publikační činnosti a níže přikládá soubor tří článků a jednoho příspěvku publikovaných v časopisech indexovaných v databázích Scopus a Web of Science, přičemž na těchto publikacích má autor zásadní podíl, jelikož se jedná o výsledky související s touto disertační prací. Autorské kolektivy jednotlivých prací dokladují splnění metodického cíle o spolupráci s oborovými specialisty. Další publikační činnost naopak představuje spolupráci autora v jiných projektech, do kterých byly poskytovány výsledky a poznání získaná v průběhu realizace výzkumných cílů této práce. Jako například spoluautorství na užitném vzoru číslo: 34497 s názvem: *Zařízení pro fermentaci a teplotní ošetření biomasy*.

Vzájemné provázání jednotlivých výsledků je znázorněno v následujícím diagramu 2, kde jsou jednotlivé komponenty provázány s níže uvedenými publikacemi.

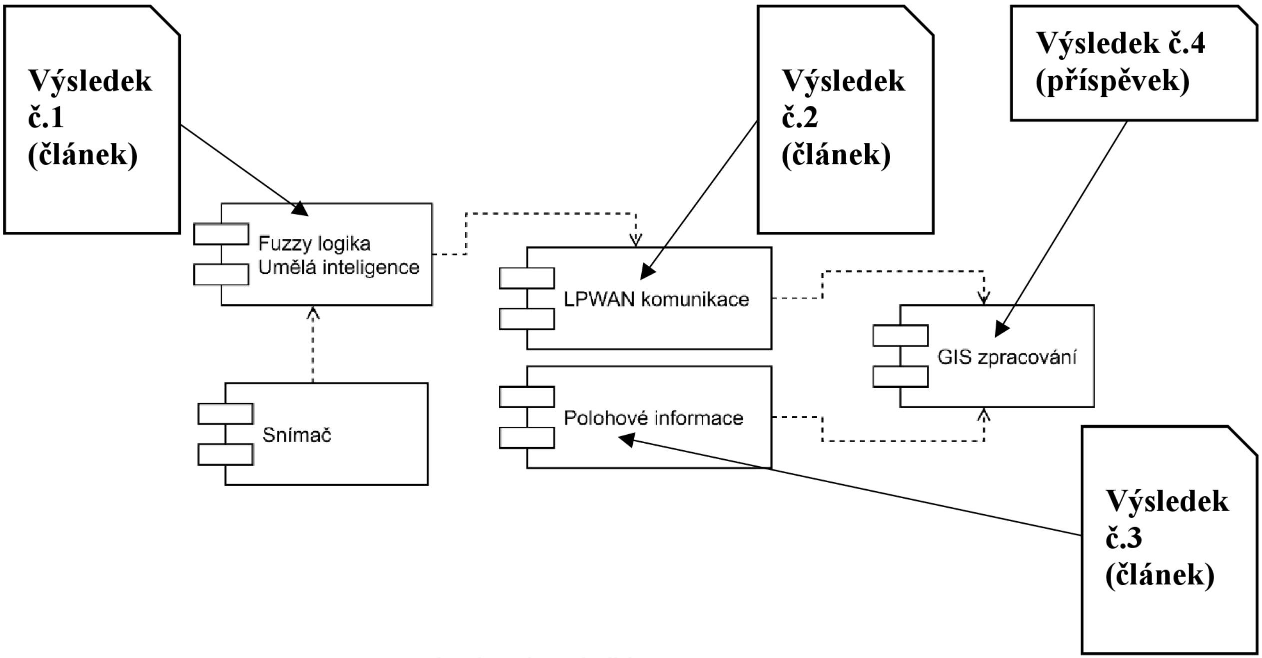


Diagram 2: Znázornění provázanosti jednotlivých výsledků

5.1 Komentář k výsledku č.1

Welfare with IoT Technology Using Fuzzy Logic. Agris on-line Papers in Economics and Informatics

První dílčí cíl práce: ověření hypotézy o využití matematických funkcí zejména podoboru Fuzzy logiky k agregaci informace samotným senzorem. V práci bylo ověřeno, že fuzzy přístup lze použít k předávání informací v již interpretované podobě.

Metodika byla nejprve aplikována na problematiku Welfare a chytré farmy. A byla zpracována publikací:

NOVÁK, Vojtěch, Jan PAVLÍK, Michal STOČES, Jiří VANĚK a Jan JAROLÍMEK, 2020. Welfare with IoT Technology Using Fuzzy Logic. Agris on-line Papers in Economics and Informatics, 111–118. ISSN 1804-1930. Dostupné z doi:10.7160/AOL.2020.120210

Bylo ověřeno, že fuzzy přístup lze použít k předávání informací stájovému personálu, který je schopen lépe rozumět informacím ve formě popisného vyjádření, které přidává kontextové informace ve vztahu ke zvířeti. Tento přístup zajistil vyšší míru optimalizace provozu díky snížení chybovosti zaměstnanců a zvýšení produkce stáje z důvodu dodržování podmínek welfare.

Po generalizaci přístupu bylo možné využít výše uvedené poznatky pro systém monitoringu výšky hladiny, kde podstatnou informací je, zda výška hladiny již může být potencionálně nebezpečná či nikoliv. Dle toho je i možné parametrizovat chování samotného senzoru a tím lze dosáhnou úspory baterie díky úpravě komunikační frekvence na základě důležitosti přenášené informace.

5.2 Komentář k výsledku č.2

Experimental Evaluation of the Availability of LoRaWAN Frequency Channels in the Czech Republic

Druhou oblastí výzkumu bylo experimentální vyhodnocení samotného radiového přenosu dat v reálném prostředí. Měřením bylo zjištěno, že významný vliv na úspěšnost doručení zprávy odeslané senzorickým zařízením v síti LoRaWAN poskytnuté společností České Radiokomunikace, a.s., má volba jednoho z osmi komunikačních kanálů, kdy takzvaně tři základní kanály jsou pro přenos ve městě prakticky nepoužitelné. Výsledky jsou pro svou kvalitu publikovány v časopise Sensors s IF 3.847:

NOVÁK, Vojtěch, Michal STOČES, Tereza ČÍŽKOVÁ, Jan JAROLÍMEK a Eva KÁNSKÁ, 2021b. Experimental Evaluation of the Availability of LoRaWAN Frequency Channels in the Czech Republic. *Sensors*, Vol. 21, no. 3, s. 940. ISSN 1424-8220. Dostupné z doi:10.3390/s21030940

Analýza odhalila anomálie ve srovnání s teoretickými očekáváními, tedy nerovnoměrnou distribuci přijatých zpráv v jednotlivých kanálech. Zařízení standartně využívá 8 komunikačních frekvencí v ISM pásmu 867,1 MHz až 868,5 MHz.

Příčina nižšího podílu doručených zpráv v případě prezentovaného výsledku, konkrétně na frekvencích 868,1 MHz a 868,5 MHz, nebyla blíže zkoumána, pravděpodobně se jedná o radiové zarušení v městském prostředí. S ohledem na to, že není možné tento stav ovlivnit, je nutné se tomto faktu přizpůsobit.

Princip navržené optimalizace spočívá v pravidelném provádění tohoto měření, které lze procesně zcela automatizovat a následně lze vždy konfiguračně vyřadit problematické frekvence pro přenos dat a tím ve výsledku zvýšit úspěšnost doručení zpráv. Díky vysoké úspěšnosti v doručování zpráv není nutné odesílat data opakovaně, či ve vysoké periodě při zachování stále stejné kvality

5.3 Komentář k výsledku č.3

Monitoring of Movement on the Farm Using WiFi Technology

Publikace souvisí s oblastí výsledků, ve které jsou prezentovány optimalizované metody získávání polohové informace s minimálními energetickými nároky.

V publikaci jsou zejména publikovány možnosti, jakými lze získat polohu IoT zařízení, a to s minimálními energetickými požadavky, tedy převážně v budovách, kde není možné polohu určit s využitím satelitních navigačních systémů, které jsou navíc významně energeticky náročné. V publikacích jsou například prezentovány výsledky experimentu určení polohy za využití technologie WiFi instalované v budově. A dále možnosti určení polohy v rámci technologie LoRaWAN, tedy metod RSSI a TDoA, kdy síť je schopna pasivně určit polohu zařízení pouze na základě jeho standartní komunikace, tedy žádným způsobem neovlivňuje životnost baterie zařízení.

NOVÁK, Vojtěch, Michal STOČES, Eva KÁNSKÁ, Jan PAVLÍK a Jan JAROLÍMEK, 2019. Monitoring of Movement on the Farm Using WiFi Technology. *Agris on-line Papers in Economics and Informatics*, s. 85–92. ISSN 1804-1930. Dostupné z doi:10.7160/AOL.2019.110408

5.4 Komentář k výsledku č.4

IoT and GIS Data Platform Solutions in Agricultural

Poslední oblastí výsledků je zpracování a vizualizace prostorových dat, kterým je věnován příspěvek publikovaný na konferenci Information Technology and Implementation 2021:

NOVÁK, Vojtěch, Lukáš KOVÁŘ, Michal STOČES a Martin HAVRÁNEK. IoT and GIS Data Platform Solutions in Agricultural. In: Aldrich Chris ANATOLY ANISIMOV, VITALIY SNYTYUK, ed. *Information Technology and Implementation 2021* [online]. B.m.: CEUR Workshop Proceedings, s. 198–210. Dostupné z http://ceur-ws.org/Vol-3132/

V příspěvku jsou publikovány vybrané metody využití GIS produktů americké společnosti ESRI pro zpracování IoT dat. Příspěvek zejména pojednává o možnostech nástroje nazývaného ArcGIS GeoEvent Server jakožto službě, která zprostředkovává propojení mezi IoT zařízeními a celým ekosystémem ostatních geografických služeb.

Metodika je aplikována a ověřena na problematice monitoringu hladiny potoka.

Agris on-line Papers in Economics and Informatics

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Welfare with IoT Technology Using Fuzzy Logic

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Abstract

The article describes the concept of deploying IoT technologies within the environment of agrarian operations using a system approach with a focus on fuzzy logic. In addition to the introductory acquaintance with IoT and fuzzy theory, the paper focuses on specific possibilities of applying the fuzzy approach, especially in the case of animal husbandry. The main benefit for this field is the fulfillment of welfare principles and the achievement of economic savings based on optimization. The article also showcases a practical implementation of a demonstrative solution in the JavaScript programming language using data from IoT sensors.

Keywords

IoT, Fuzzy Logic, Welfare, Networks, Precision Agriculture, Smart Agriculture, JavaScript.

Novák, V., Pavlík, J., Stočes, M., Vaněk, J. and Jarolímek, J. (2020) “Welfare with IoT Technology Using Fuzzy Logic", *AGRIS on-line Papers in Economics and Informatics*, Vol. 12, No. 2, pp. 111-118. ISSN 1804-1930. DOI 10.7160/aol.2020.120210.

Introduction

Technological solutions, such as the modern IoT (Internet of Things), can solve problems or bring about the optimization of existing processes, but only if they can naturally interact with the environment in which they are deployed.

This approach is best suited for implementations of continuous, i.e. analog systems, which can respond to change immediately in almost an unlimited number of levels. However, to be able to apply the available numerical methods to these systems, digitization is necessary. This allows to express reality using a discrete approach with a limited number of levels. Therefore it is necessary to focus on those principles of IoT that are based on the discrete approach, for example that the measurement takes place only a few times over a defined period (sampling) and the values are quantized to predefined levels (Rymarczyk, 2020).

IoT issues are more increasingly important and experience dramatic development in many areas. Such development brings many new technological innovations as well as generated new problems. Vast quantities of IoT devices in use or still in development need to be categorized based on their usage, type, internet connection, place of implementation etc. One of the important places of usage is agrarian sector and countryside in general. It belongs to one of the more “traditional” areas of IoT implementation, but there is still a lot of room for further development (Stočes et al., 2016).

Fuzzy logic and IoT technology were also presented as a strategy to develop an intelligent irrigation approach that fosters water conservation and better irrigation management in areas with high levels of water stress. The developed fuzzy controller, based on Mamdani fuzzification using trapezoidal and triangular membership functions, efficiently set the time and duration of irrigation for a given crop. The use of fuzzy control helped maintaining the moisture above a pre-set value with smooth variations preventing frequent system’s run-off and preserving water and energy. To monitor system in real time, a wide-range ZigBee based wireless network was also used. The system is easy to implement, and economically justifiable (Alomar and Alazzam, 2019).

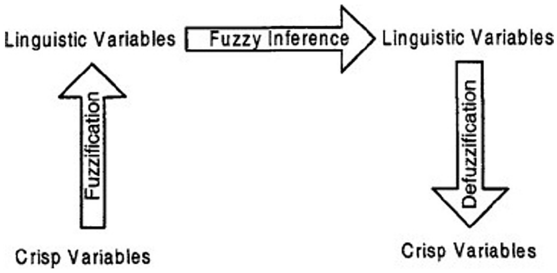
The combination of IoT and fuzzy logic is also being successfully used is various non-agriculture applications. For instance, the fuzzy logic model was used to control the intensity of light emitted by lighting. Using this approach, it is possible to enlighten the environment according to the conditions and not waste energy by producing excessive lighting (Altun and Dörterler and Doğru, 2018). Another possible application of this approach is in fashion retail as described by (Chan, Lau and Fan, 2018).

Materials and methods

Fuzzy logic is fundamentally built upon the concept of fuzzy sets (Rezaee and Kadkhodaie-Ilkhchi and Alizadeh, 2008). Even though the gradual evolution of the expression of uncertainty using probability theory was challenged first in 1937 by Max Black (Ross, 2004), Lofi Zadeh at the University of California initiated research into fuzzy logic approach in 1965. Since then, fuzzy logic has fully come of age. Its foundations have become firmer, its applications have grown in number and variety, and its influence within the basic sciences, especially in mathematical and physical sciences, has become more visible and more substantive. Yet, there are two questions, that are still frequently raised: a) what is fuzzy logic and b) what can be done with fuzzy logic that cannot be done equally well with other methodologies, e.g., predicate logic, probability theory, neural network theory, Bayesian networks, and classical control? One suggested answer is that the main contribution of fuzzy logic is a methodology for computing with words, as no other methodology serves this specific purpose. A fuller exposition of the methodology of computing with words (CW) will appear in a forthcoming paper. Needless to say, there is more to fuzzy logic than a methodology for CW (Zadeh, 1996).

In general, the fuzzy inference system consists of four modules, the first one is the fuzzification module that transforms the system inputs which are crisp numbers, into fuzzy sets. The second module is called knowledge base, it stores the IF-THEN rules, the rules normally specified by experts. The third module is called the inference engine, it simulates human reasoning process by making fuzzy inference on the inputs and IF-THEN rules. The fourth and last one is called defuzzification module that uses inference engine to transforms the fuzzy set into a crisp value (Fayaz and Kim, 2017).

The following Figure 1 shows the above process where the second and third mudules are merged into a fuzzy inference step.

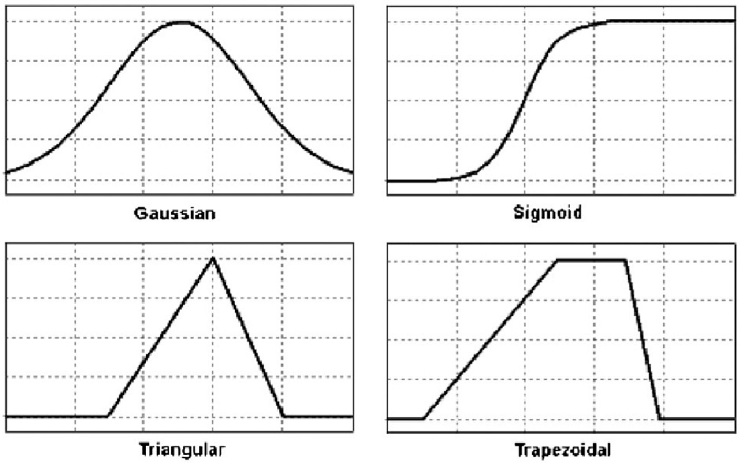


Source: Wang, 2001

Figure 1: Fuzzy logic concept.

Fuzzification

Fuzzification is a step to determine the degree to which an input data belongs to each of the appropriate fuzzy sets via the membership functions (Xu, 2010). In fuzzy logic, a fuzzy inference system is used as a procedure, in which the input is converted in to fuzzy sets with the help of membership functions like for instance: triangular, trapezoidal, gaussian, or sigmoidal (Patel and Champaneria, 2017) (see Figure 2).



Source: Rezaee and Kadkhodaie-Ilkhchi and Alizadeh, 2008

Figure 2: Four types of fuzzy membership functions: Gaussian, sigmoid, triangular and trapezoidal.

Membership functions

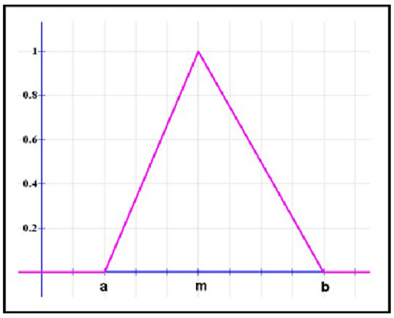
Definition: a membership function for a fuzzy set A on the universe of discourse X is defined as μA:X → [0,1], where each element of X is mapped to a value between 0 and 1. This value, called membership value or degree of membership, quantifies the grade of membership of the element in X to the fuzzy set A. Membership functions allow us to graphically represent a fuzzy set. The x axis represents the universe of discourse, whereas the y axis represents the degrees of membership in the [0,1] interval (Alonso, [no date]).

Below is the list of membership functions we will use in our experiment:

Triangular function: defined by a lower limit **a**, an upper limit **b**, and a value **m**, where

a < m < b. It is described in formula (1), and shown in Figure 3 (Alonso, [no date]).

$$\mu_A(X) = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{m-a}, & a < x \leq m \\ \dfrac{b-x}{b-m}, & m < x < b \\ 0, & x \geq b \end{cases} \tag{1}$$

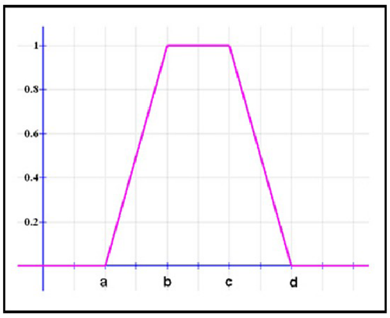


Source: Alonso, [no date]

Figure 3: Triangular function.

Trapezoidal function: defined by a lower limit **a**, an upper limit **d**, a lower support limit **b**, and an upper support limit **c**, where **a < b < c < d**. t is described in formula (2), and shown in Figure 4 (Alonso, [no date]).

$$\mu_A(X) = \begin{cases} 0, & x > d \\ \dfrac{d-x}{d-c}, & c \leq x \leq d \\ 1, & x < c \end{cases} \tag{2}$$

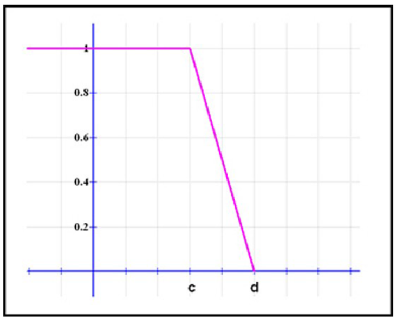


Source: Alonso, [no date]

Figure 4: Trapezoidal function.

Grade function: with parameters **a = b = -** ∞. It is described in formula (3), and shown in Figure 5 (Alonso, [no date]).

$$\mu_A(X) = \begin{cases} 0, & x < a \\ \dfrac{x-a}{b-a}, & a \leq x \leq b \\ 1, & x > b \end{cases} \tag{3}$$

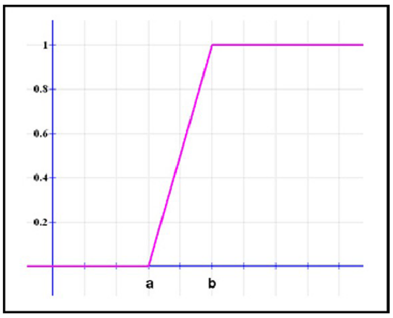


Source: Alonso, [no date]

Figure 5: Grade function.

Reverse Grade function: with parameters **c = d =** + ∞**.** It is described in formula (4), and shown in Figure 6 (Alonso, [no date]).

$$\mu_A(X) = \begin{cases} 0, & x < a \\ \dfrac{x-a}{b-a}, & a \leq x \leq b \\ 1, & x > b \end{cases} \tag{4}$$



Source: Alonso, [no date]

Figure 6: Reverse Grade function.

Knowledge Base

A system of fuzzy IF-THEN rules is considered as a knowledge-based system where inference is made on the basis of three rules of inference (Perfilieva, 2007). The 'noun' is often unimportant in the applications. Therefore, it is commonly replaced by some variable X whose values are not the objects themselves but only its features, such as height, volume, tension, size, abstract degrees of beauty, temperature, etc. This leads us to the concept of a fuzzy IF-THEN rule which is a kind of "abstracted" compound adjectival predication.

Definition: By fuzzy IF-THEN rule we understand either of the compound adjectival predications R^1 and R^A taken in the form of formulas (5) and (6), where X and Y represent features of objects (Novák and Lehmke, 2006).

$$\mathcal{R}^A := X\ is\ \mathcal{A}\ AND\ \ Y\ is\ \mathcal{B} \tag{5}$$

$$\mathcal{R}^1 := IF\ is\ \mathcal{A}\ THEN\ \ Y\ is\ \mathcal{B} \tag{6}$$

As an example, in practical implementation, such a rule can look like this:

IF it is hot, **THEN** ventilate a lot.

Fuzzy inference

Fuzzy inference is a method that interprets the values in the input vector and based on sets of rules, assigns values to the output vector. In fuzzy logic, the truth of any statement becomes a matter of a degree. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made or patterns discerned (Kala, 2016; Kalogirou, 2014).

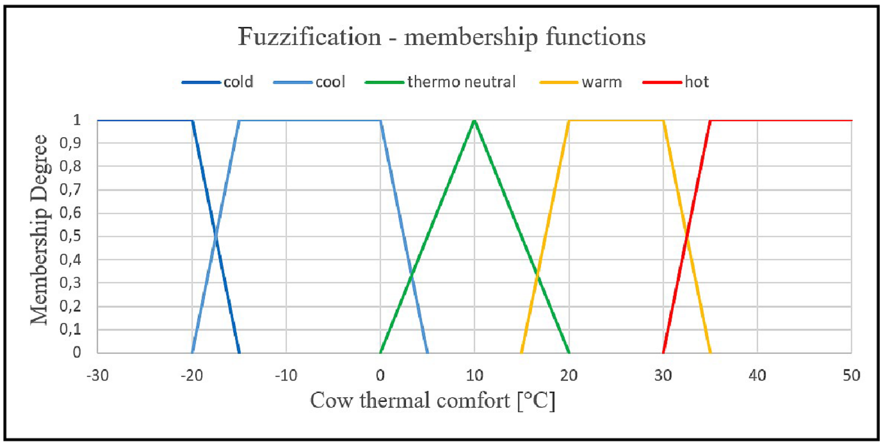
Defuzzification

Defuzzification is the process of obtaining a single number from the output of the aggregated fuzzy set. It is used to transfer fuzzy inference results into a crisp output. In other words, defuzzification is realized by a decision-making algorithm that selects the best crisp value based on a fuzzy set. There are several forms of defuzzification including center of gravity (COG), mean of maximum (MOM), and center average methods. The COG method returns the value of the center of area under the curve and the MOM approach can be regarded as the point where balance is obtained on a curve (Masoum and Fuchs, 2015; Patel and Champaneria, 2017).

Experimental Implementation

The aim of the experiment was to determine whether it is possible to apply the theory of fuzzy systems to ensure compliance with the principles of welfare in the environment of animal husbandry. The term "animal welfare" is being used increasingly by corporations, consumers, veterinarians, politicians, and others. However, the term can mean different things to different people. Understandably, in the past, veterinarians and farmers have seen animal welfare chiefly in terms of the body and the physical environment (shelter, feed, etc.). Meaning that if an animal is healthy and producing well, it is faring well. Research on aspects of animal welfare has also mainly focused on the body, using physiological measures, such as endorphins, plasma cortisol, and heart rate, to examine how the animal is coping with its environment. However, there are limitations to seeing animal welfare only in terms of the body. One limitation is that genetics and the environment can produce desirable physical outcomes, even though the animal's mental state is compromised. For example, a canine breed champion may have perfect conformation and be in perfect health, but it may be very anxious in its home environment. Another limitation is that some physical parameters (heart rate, plasma cortisol) are difficult to interpret, because they can be increased by both positive and negative experiences, such as the presence of a mate and the presence of a predator (Hewson, 2003; Broom, 1991; Blood and Studdert and Carling, 1988).

The main purpose of the experiment was to create a system that could better inform farmers about the needs of his animals. The air temperature was chosen for the experiment for clarity, as it is an important element of the stable microclimate. Together with other physical characteristics (air flow, relative humidity) it most influences the thermal state of the animal organism and its thermal well-being. In a certain temperature range, at constant values of other physical elements, the thermal state of the organism is considered optimal, as the animal has only a small expenditure of energy to maintain physiological functions and has a feeling of thermal well-being (comfort). This temperature range is the so-called "thermoneutral zone", which is much wider in cattle, as well as in other ruminants (such as sheep), than in monogastric animals. In addition to species affiliation, it is also affected by other factors, especially the overall level of metabolism (Doležal et al, 2004).

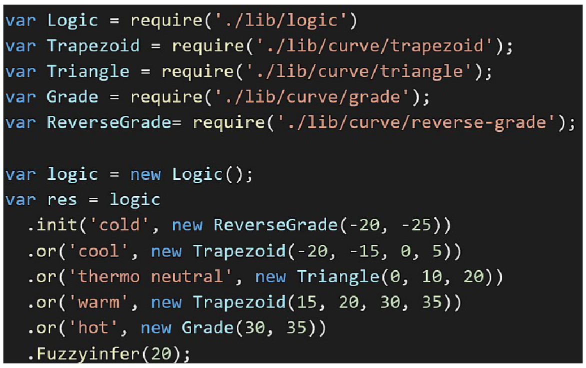


Source: own processing

Figure 7: Fuzzification – membership functions.

Based on a literature search, especially the relevant legislation, the following five fuzzy sets have been defined, which will be used for fuzzification (see Figure 7) (No. 208/2004 Coll., 2004; 98/58 / EC, 2017).

Fuzzy logic sets are implemented by the JavaScript programming language. The experiment was based on the Open Source library "es6-fuzz" (Schürmann, 2019), which was embedded into the program for the experiment. The following example program (see Figure 8) shows the creation of membership functions according to their respective graphs. The definition of the shape of individual curves is solved by including partial libraries.



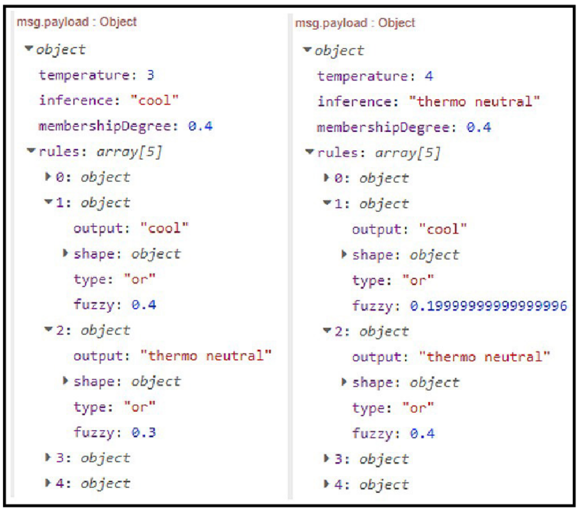
```javascript
var Logic = require('./lib/logic')
var Trapezoid = require('./lib/curve/trapezoid');
var Triangle = require('./lib/curve/triangle');
var Grade = require('./lib/curve/grade');
var ReverseGrade= require('./lib/curve/reverse-grade');

var logic = new Logic();
var res = logic
  .init('cold', new ReverseGrade(-20, -25))
  .or('cool', new Trapezoid(-20, -15, 0, 5))
  .or('thermo neutral', new Triangle(0, 10, 20))
  .or('warm', new Trapezoid(15, 20, 30, 35))
  .or('hot', new Grade(30, 35))
  .Fuzzyinfer(20);
```

Source: own procerssing

Figure 8: Sample javascript program.

Figure 9 shows the function of the program. It is a JSON data structure, with attributes showing program variables. The office entry was at temperature of 3 ° C and 4 ° C, the inference item shows with what word the program qualified the given value and “membershipDegree” constitutes the degree of belonging to the given set.



```
msg.payload : Object
▾object
  temperature: 3
  inference: "cool"
  membershipDegree: 0.4
 ▾rules: array[5]
   ▸0: object
   ▾1: object
      output: "cool"
     ▸shape: object
      type: "or"
      fuzzy: 0.4
   ▾2: object
      output: "thermo neutral"
     ▸shape: object
      type: "or"
      fuzzy: 0.3
   ▸3: object
   ▸4: object
```

```
msg.payload : Object
▾object
  temperature: 4
  inference: "thermo neutral"
  membershipDegree: 0.4
 ▾rules: array[5]
   ▸0: object
   ▾1: object
      output: "cool"
     ▸shape: object
      type: "or"
      fuzzy: 0.19999999999999996
   ▾2: object
      output: "thermo neutral"
     ▸shape: object
      type: "or"
      fuzzy: 0.4
   ▸3: object
   ▸4: object
```

Source: own procerssing

Figure 9: JSON data structure.

Results and discussion

It has been verified that the fuzzy approach can be used in a very simple way to pass information to the stable staff, where it is better understood by humans in a form of a verbal expression that adds contextual information in relation to the animal.

Thanks to this approach, greater optimization of operation can be achieved, which reduces the error rate of the employees and increases the production of the stable due to compliance with welfare conditions. Fuzzy approach can therefore directly lead to an economically positive effect.

For fully automated operations, it will be necessary to use the knowledge base and subsequent defuzzification for automatic intervention, which was not the goal of this experiment. It would require specialized professionals so that the control circuit can be set optimally.

Fuzzy control itself is a very widespread and standard tool. For example, the Japanese have been quickest to apply fuzzy logic in 1989. A fuzzy system developed by Hitachi was already used to control subway trains in the city of Sendai, accelerating and decelerating cars more smoothly than a human driver could (Pollack, 1989).

Conclusion

Apart from its usage in agriculture, utilization of fuzzy approach in conjunction with IoT can be for example aimed at developing an energy-saving thermometer for measuring the temperature of the human body. The results show that HI-Thermo saves energy of monitoring significantly. Using fever body temperature measurements, the proposed system consumes 15% lower than the existing traditional monitoring of body temperature, which does not implement fuzzy logic (Mandala et al, 2017).

It would be appropriate to evaluate the benefits of the use of these technologies, similar to the work assessing the benefits of precision farming technologies in sugar beet production. (Jarolímek et al, 2019)

A secondary output of this research is the finding, that fuzzy logic can be beneficial for IoT devices themselves, regardless of industry use. An important opportunity for the use of fuzzy approach, as outlined here is the implementation of algorithms directly into battery powered IoT devices, which will achieve significant aggregation of information and thus save energy in wireless communication. Alternatively, the capabilities of fuzzy logic can be used for instance in forecasting. The field of fuzzy logic still experiences very active theoretical research, so there is high possibility for new knowledge and approaches to emerge in the near future (Fayaz and Kim, 2017).

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sensors

Communication

Experimental Evaluation of the Availability of LoRaWAN Frequency Channels in the Czech Republic

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Abstract: LoRaWAN communication allows you to create IoT (Internet of Things) solutions across many disciplines. A specific field of application is precision agriculture, which demands this technology mainly due to the fact that it is possible to create low power sensor devices with it. However, in densely populated areas, a lower success rate of message delivery can be observed on some communication channels. For example, this can have an impact on urban agriculture projects. After performing an experiment and analytical–statistical data processing using the Geographic Information System (GIS) tool ArcGIS Insights, it was shown that the success of message delivery on the basic LoRaWAN channel (868.3 MHz) is lower than for the others. Therefore, to ensure higher reliability and thus energy savings, it is appropriate to optimize the use of frequency channels.

Keywords: LoRaWAN; LPWAN; IoT; signal; ESRI; GIS; ArcGIS insights; frequency; device; experiment

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1. Introduction

LoRaWAN communication can be used for example in areas such as smart cities, industrial applications, precision agriculture, and many more. It is very important for further research to gain detailed experience from the practical deployment of LoRaWAN technology. Based on this knowledge, the technology itself can be improved, or other monitoring solutions can be found.

In the context of my work and activities at the Czech University of Life Sciences within the solved agricultural projects of my colleagues from the university, this work focuses on the evaluation of technological environments for these research projects aimed at the field of agriculture. For example, our university team has previously published that: "IoT technologies are currently the most developing area of telemetry transmissions in both industrial and agricultural environments" [1]. In most cases, it is essential for these projects that the equipment be a so-called low power, such as monitoring beehives, using beehive scales measuring the weight of the beehive and some other parameters—for example, indoor temperature and relative humidity of the hive [2].

The success of these projects often depends on the reliability of the used technologies and also on its appropriate use. Thanks to the availability of LoRaWAN technology in the Czech Republic with the use of a nationwide operator, it is possible to consider using it for the needs of agriculture within the Czech Republic.

LoRaWAN wireless technology offers a Star topology using stochastic network access (Aloha) at the wireless level. Spread spectrum modulation with an optional spreading factor parameter is used. A message sent by one device is received on many different gateways when it is forwarded to a central point of the network, the so-called network server, which combines the individual messages into one [3].

2. Related Work

A review of the available literature has shown that many studies and experiments have been published. For example, a significant factor affecting all Low Power Wide Area Networks (LPWAN) is the legislative restrictions addressed for example as Impact of EU duty cycle and transmission power limitations [4]. An alternative technology to LoRaWAN is Sigfox [5], which it compares with each other by Vejlgaard et al. [6].

The importance of the use of LoRaWAN technology in agriculture can be observed, for example, in the study, "A Case Study in Kenya [7] and LoRaWAN in Industrial 4.0 Environments" [8].

Technology is often studied in laboratory conditions, as it is able to function on its own, for example in terms of capacity as stated by many authors, e.g., [6,7]. Martina Capuzzo created a mathematical model describing LoRaWAN Performance with Bidirectional Traffic [9].

For example, practical verification of the spread of LoRaWAN within the university campus can be found in Rabey Anzum, who worked with the 3D ray tracing method [9], similar to the team from the University of Duisburg-Essen [10]. However, most studies focus on a targeted verification of technological possibilities, or on improving Quality-Of-Service in LoRaWAN through Optimized Radio Resource Management as settings parameters (ADR, SF, CSS, channels, etc.) [10–12]. The consequences of such optimization have an impact on energy consumption, which is also addressed by several authors, as exemplified: "Comparison of LoRaWAN Classes and their Power Consumption" [13].

To a small extent, the results of operating parameters in the actual deployment of technology outside the laboratory environment are published, such as the work of an Italian team led by Lorenzo Parri, who tested the possibilities of using connectivity at sea [14]. However, interference cannot be expected there, as is the case, for example, in the city center, and this is the topic of this article. This article went a different way, namely to obtain operational metadata from the actual installation of the sensor, where the payload itself is used for another experiment, and find out what information these metadata are able to provide. During the testing of the usability of the LoRaWAN technology for the needs of Urban Agriculture, a three-day measurement was performed in Prague, the capital of the Czech Republic. After analytical and statistical data processing, some interesting phenomena were revealed. This work tries to approach them, but it does not solve their direct cause; instead, it tries to establish a hypothesis.

3. Materials and Methods

Metadata obtained from the LoRaWAN network of the Czech operator called České Radiokomunikace in a special test mode were used for the experiment. The device used a Murata communication module [15] with a built-in network layer. Thus, the behavior of the device on the network is given by the manufacturer Murrata. The device sent a data message approximately every two minutes, and 1000 individual received messages were selected for the experiment to obtain data for approximately three days of the experiment. The legislative duty cycle limit was not reached; sending one message took 51 ms and 92 ms, depending on the current data rate. The experiment did not evaluate the success of delivery, but it did conduct a mutual statistical comparison of successfully received messages.

Necessary transformations were performed with the data. The data structure provided by the network is structured into a JSON document with a variable message length. The structure of the messages thus received includes a common data part comprising attributes e.g., Receive timestamp, Data rate used, Communication frequency (channel), Message transmission time, Frame counter, sequence number, etc. For the part with the metadata field obtained from individual gateways, for each gateway, its ID, its geographical location, signal parameters RSSI (Received Signal Strength Indication) and SNR (Signal-to-Noise Ratio), and some other attributes are given. In order to be able to process the data in the intended analytical tool, a new data structure had to be designed. The data were converted to GeoJSON data format using the function in Appendix B, which were further supplemented with the position information of the place where the sensor was located; also, a unique message identifier was created by combining "seqno" and "fcnt" attributes, which was added to the respective GW messages so that the data could be divided into two GeoJSON files.

As this is data containing position information, the Geographic Information System (GIS) platform, specifically ArcGIS Insights, was used to analyze it, into which the files prepared in this way can be loaded. In order to analyze the data together, a prepared identifier was used to create a 1:N session, which corresponds to the fact that a message sent by one device was received by many gateways.

For processing and analyzing the data, we used the ArcGis Insights tool, which allows a direct data connection. This tool offers many easily accessible tools for working with data. In particular, it is possible to visualize data using graphs and maps. Data can be read in MS Excel format or in GeoJSON format, and data can be composed in the tool using sessions. Individual views are created from the prepared datasets using drag-and-drop. Individual graphic elements offer dynamic redrawing based on the selection in the linked element [16].

A very useful tool that was used for the analysis is the Boxplot view. A description of the meaning of individual elements is available on the manufacturer's website [17].

4. Results

4.1. Experiment introduction

This section describes basic information about the course and duration of the experiment. The experiment lasted for the period from 6:40 p.m. 23 November 2020 to 9:20 a.m. 25 November 2020, where the operator-certified testing device sent a data message every two minutes. The device had ADR activated, and during the experiment, the network server set up automatically the Spreading Factor value, which ranged between SF7 and SF8. The device was located approximately in the city center, and during the entire experiment, messages sent by the device were delivered to 14 gateways of the largest Czech LoRaWAN operator, as shown in Figure A1 in Appendix A.

According to the value of the frame counter contained in the metadata, it is possible to determine the total success rate of message delivery, which reached 84%, where 1192 messages were sent for 1000 successfully received messages. Undelivered messages are distributed evenly, where the maximum number of undelivered consecutive messages was 4, and only in one case. A detailed view of undelivered messages is indicated in the following Table 1 below.

Table 1. Numbers of consecutive undelivered messages broken down by groups.

Group [1]	Occurrence	Undelivered
1	136	136
2	23	46
3	2	6
4	1	4

[1] The group value indicates the number of undelivered messages in a row.

4.2. Signal Analysis

Subsequently, the data were analyzed analytically in ArcGIS Insights, and one of the outputs that was focused on evaluating the success of message delivery showed that one first basic channel (868.1 Mhz) shows a significantly below-average number of received messages. For this channel, the GW was displayed on the map (in Appendix A, Figure A2) that received the message on this channel. An overview is shown in Figure 1.

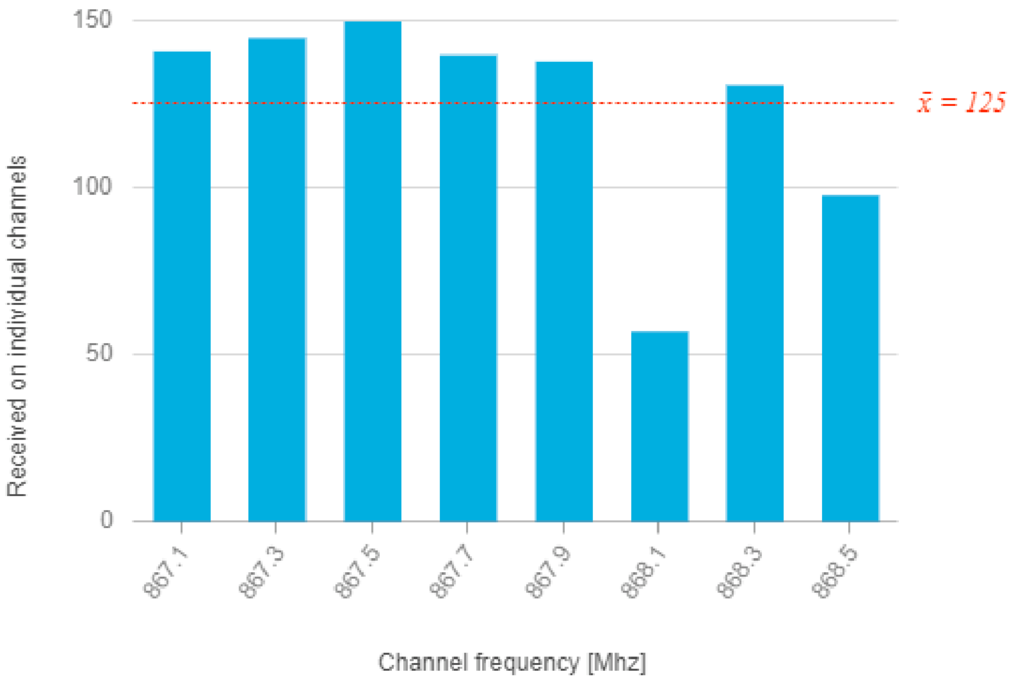

Figure 1. Number of received messages within individual LoRaWAN channels.

The data were further statistically processed and visualized using two boxplot graphs, where the first graph shows the relationship between the specific frequency channel and RSSI received messages (Figure 2), and the second graph shows the relationship between frequency channel and SNR (Figure 3).

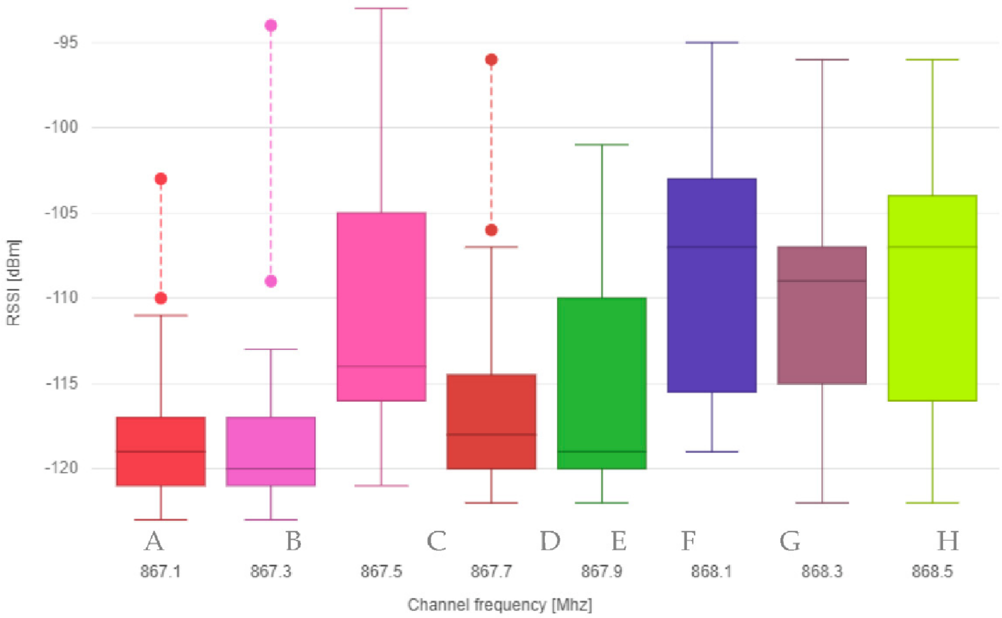

Figure 2. Boxplot graph for frequency channel and RSSI.

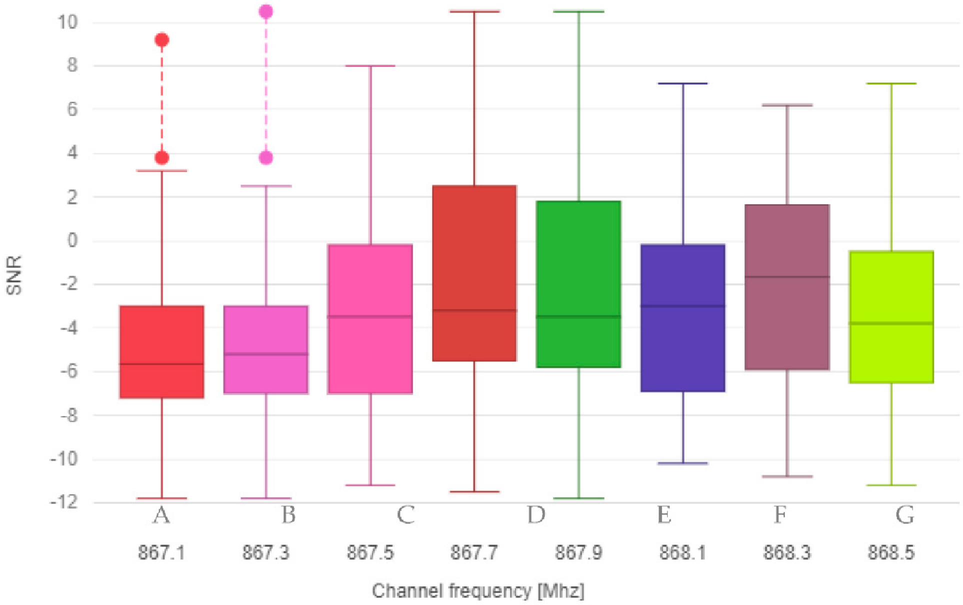

Figure 3. Boxplot graph for frequency channel and SNR.

The interference hypothesis is also supported by Figure 4, where the relationship between signal strength and SNR. The spreading factor, was set to automatic and ranged between SF7 and SF8, which is marked in color in the graph.

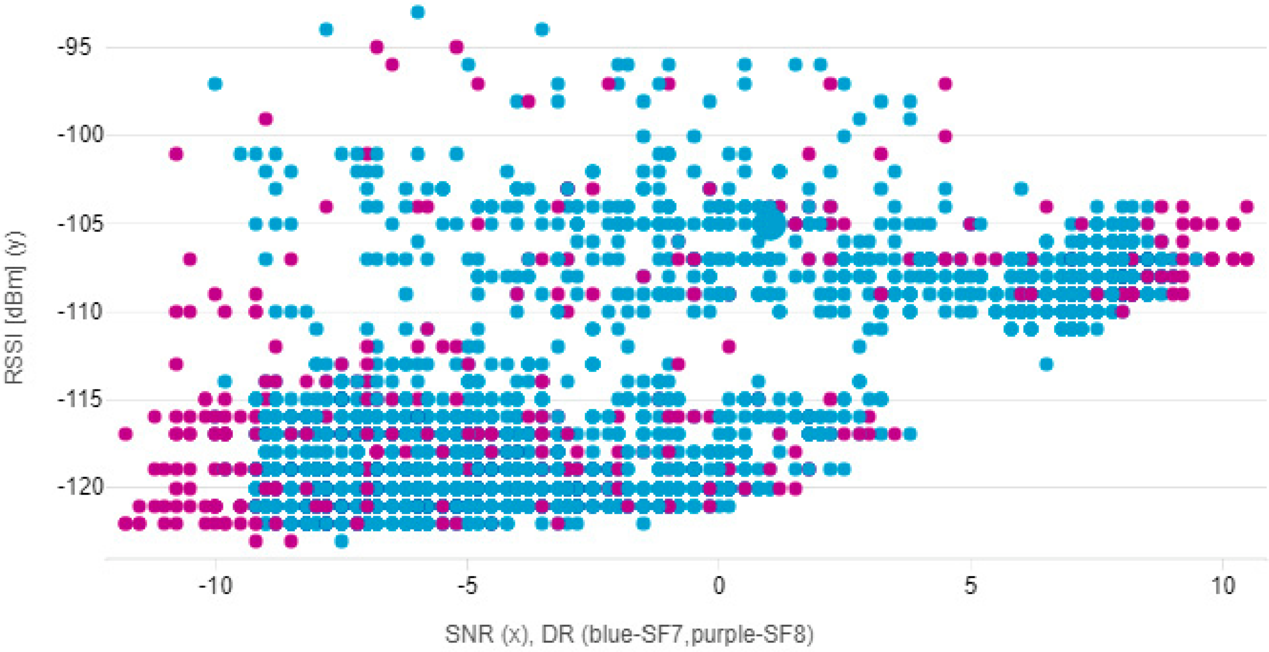

Figure 4. Scatter plot shows the relationship between signal strength and signal-to-noise ratio. The color resolution shows the currently selected spreading factor.

5. Discussion

This study describes the detected state measured in a real environment, which was analytically processed. The analysis revealed anomalies compared to theoretical expectations. Thus, an uneven distribution of received messages in individual channels. The most likely cause of the lower proportion of messages delivered on the 868.1 Mhz and 868.5 MHz channels will be local interference from other traffic in this ISM band. This assumption can be verified by direct measurement using a spectrum analyzer, but such measurement would have to take place simultaneously over a large area.

This result is also interesting to evaluate depending on the LoRaWAN specification, where it is given that channels corresponding to 868.1, 868.3, and 868.5 MHz shall be implemented but cannot be modified, according to the protocol specification [18]. Adding other channels in larger quantities can increase delivery success. Mitigation techniques can also be discussed in the contribution to reliability [19], but the article focuses on the practical life of currently commercially available technology; it is not possible to consider complex methods that are not supported in the standard, but as [20] indicated, improving the reliability could have a significant positive impact on energy consumption.

It is not possible to exclude these channels from use, although it would be possible to increase the success of message delivery. The observed results may also be related to the conclusion of the work of Georgiou and Raza, who investigated the effects of interference in a single gateway LoRa network [21]. Researchers at the University of Tokyo say that by detecting interference, the delivery success rate can be increased by 10% [22]. Frequency interference modeling was also handled by the French team [23], and the issue of mutual interference (here collisions) can also be found in the work “Improving channel utilization of LoRaWAN by using novel channel access mechanism” [24].

Frequency interference modeling is also being investigated by the French team [20], and the issue of mutual interference (collisions) can also be found in the study “Improving channel utilization of LoRaWAN by using a new channel access mechanism” [21], the results of which do not indicate the cause of the significant decrease in success in delivery on basic channels.

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Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to he data contains sensitive data, in particular accurate location information about the third party infrastructure.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

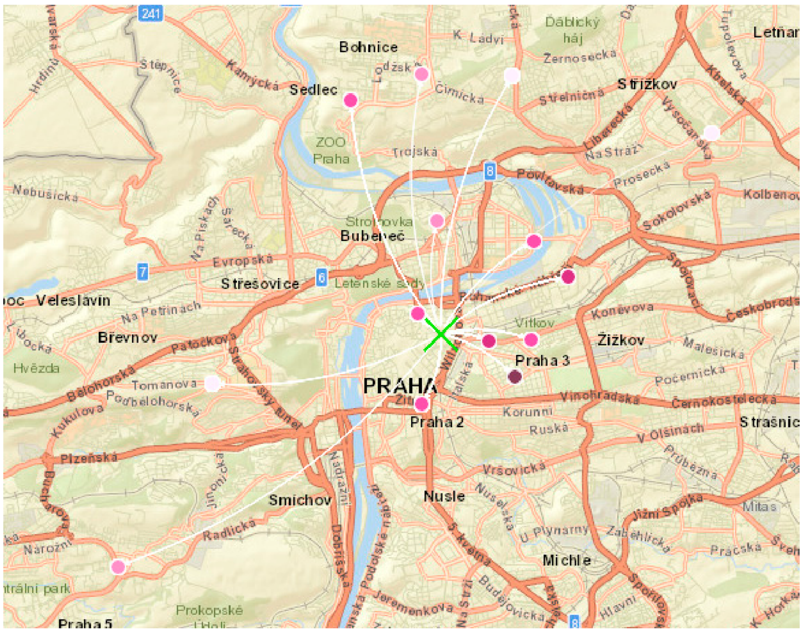
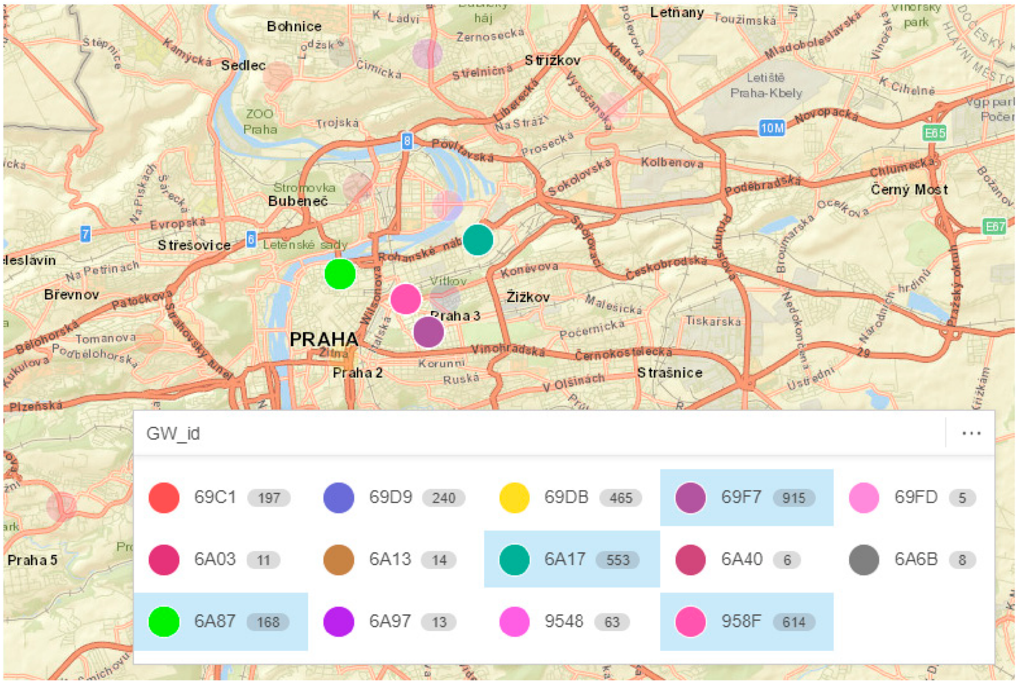


Figure A1. This image shows the geographical location of all 14 gateways that received a message from the device during the experiment. The color range of the dots corresponds to the frequency of received messages. The green cross shows the place from which it was broadcast.



GW_id

● 69C1 197	● 69D9 240	● 69DB 465	● 69F7 915	● 69FD 5
● 6A03 11	● 6A13 14	● 6A17 553	● 6A40 6	● 6A6B 8
● 6A87 168	● 6A97 13	● 9548 63	● 958F 614	

Figure A2. In the picture, you can see the table of individual gateways, where the number in the gray field indicates the number of received messages. The blue-colored fields are those gateways that have received a message on the frequency of 868.1 MHz.

Appendix B

The following code shows the transformation of a message received from a network server into GeoJSON format.

```
    function toGeoJSON(item, index) {
        var coordinates_id = item.seqno.toString() + ”-” + item.fcnt.toString()
        for (i = 0; i < item.gws.length; i++) {
            var dato = {
                ”id”: id,
                ”geometry”: {
                    ”type”: ”Point”,
                    ”coordinates”: [
                        item.gws[i].lon,
                        item.gws[i].lat
                    ],
                    ”crs”: {
                        ”type”: ”name”,
                        ”properties”: {
                            ”name”: ”EPSG:4326”
                        }
                    }
                },
                ”properties”: {
                  ”rssi”: item.gws[i].rssi,
                  ”snr”: item.gws[i].snr,
                  ”ts”: new Date(item.gws[i].ts).toISOString().replace(‘T’,”).substr(0, 23),
                  ”tmms”: item.gws[i].tmms,
                  ”gweui”: item.gws[i].gweui,
                  ”signal_index”: item.gws[i].signal_index,
                  ”coordinates_id”: coordinates_id
                },
                ”type”: ”Feature”
            }
            id++
            features.push(dato);
        }
    }
```

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Monitoring of Movement on the Farm Using WiFi Technology

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Abstract

The paper deals with using commercial WiFi solutions that provide wireless connection to computer networks to monitor the movement of devices within that network. Current technologies, in particular in the IoT area, make it possible to place a battery sensory device on individual objects used on the farm. These sensors, in addition to their primary ability to provide connectivity, can also be used to monitor the movement of the devices they are attached to. Indirectly, it is therefore possible to monitor the movement of objects, people and animals that are associated with this WiFi or Bluetooth device. An example could be the monitoring of the feed wagon's movement on the farm, while obtaining information about the actual amount of cargo. This allows for optimizing logistics operations or track the movement of employees with fitness bracelets. The aim of the paper is to verify the possibilities of currently available commercial wifi systems and their use for monitoring movement on the farm.

Keywords

Wi-Fi, Cloud, protocols, networks, position, Meraki, Aruba, Precision Agriculture, Smart Agriculture.

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Introduction

Farms are increasingly starting to build a communication infrastructure for wireless Internet access (WiFi). This paper acknowledges that fact and tries to find further possible uses for such networks and determine potential negative implications resulting from building these networks. For example, farmers can ensure better monitoring of the environment by using IoT sensors, offering better tools for employee collaboration, or helping to save lives and property. Mainly thanks to localization and monitoring of movement of specific objects, assuming that the objects in question are tied to a specific WiFi or Bluetooth device.

One of the core technologies for disaster management is the indoor positioning system, which can help rescue more people and prevent property loss due to the accurate and rapid localization of people and assets at the beginning of a disaster (Li et al., 2019; Kola-Bezka et al., 2016).

Internet of Things (IoT) issues are increasingly more important and experience dramatic development in many areas. Such development brings many new technological innovations as well as generates new problems. Vast quantities of IoT devices in use or still in development need to be categorized based on their usage, type, internet connection, place of implementation etc. One of the important places of usage is agrarian sector and countryside in general. It belongs to one of the more “traditional” areas of IoT implementation, but there is still a lot of room for further development (Stočes et al., 2016).

Underground mine locomotive monitoring and tracking management system expands mining rail net existing capacity, to increase traffic density of mining locomotive, real-time provide the position information, avoid traffic accidents and greatly enhance the transportation safety and production efficiency (Song and Liu, 2011).

Experimental results show that location system has accuracy about of 96% within 2.5 metres. However, this is only when three access point are available for establishing the position; in other cases, the accuracy is reduced. It is possible to combine the triangulation method with probability distributions of received signal strength to improve these results as shown by (Sanchez et al., 2006).

(Vasisht et al., 2016) presents Chronos, a system that measures sub-nanosecond time-of-flight on commercial WiFi radios. Chronos uses these measurements to enable WiFi device-to-device positioning at state-of-the-art accuracy, without support of additional WiFi infrastructure or non-WiFi sensors. By doing so, Chronos opens up WiFi-based positioning to new applications where additional infrastructure and sensors may be unavailable or inaccessible, e.g., geo-fencing, home occupancy measurements, finding lost devices, maintaining robotic formations, etc.

Most authors are more concerned with the issue from the perspective of the technological possibilities, and most solutions presented use proprietary systems, for example (Longo et al., 2019; Jermolajeva et al., 2017; Zelazny, 2017). While the aim of this article is to verify the possibilities of currently available commercial systems, or to compare them with each other.

Materials and methods

The following principles, methods and technologies were used in the research at the Faculty of Economics and Management at Czech University of Life Sciences Prague. We focused on methods of monitoring the movement of logistic elements within the farm using commercial solutions for management of WiFi networks.

1. Signal attenuation (RSSI method)

RSSI was considered as a metric in most of the distance measurement algorithms. Even though the ineffectiveness of RSSI is mentioned in the literature, not many attempts were made to implement it in a practical environment and verify it. (Elnahrawy et al., 2004; Parameswaran et al., 2009) have explored the idea of using RSSI in localization algorithms conducted in indoor environments and determined that more complex models and algorithms are required to improve accuracy of RSSI based methods when used indoors.

The advantage of using the signal attenuation is that no specialized hardware is required as the transmitter module measures the signal strength anyway. Imprecision in the distance estimation can occur though, caused by signal attenuation that is introduced by obstacles or reflections. This raises a major problem for indoor environments, where no simple signal propagation model can be applied unlike in a free space environment. For this reason, in indoor setups the signal attenuation is usually only used as an attribute for the subsequently described fingerprinting technique where the signal strength is measured in advance at different locations of the site (Fuchs et al., 2011).

Algorithms based on matching and signal-to distance functions are unable to capture the myriad of effects on signal propagation in an indoor environment. While many of the algorithms can explore the space of this uncertainty in useful ways, e.g., by returning likely areas and rooms, they cannot provide precise position. Still, the localization accuracy is significant and useful, as showed when mapping the objects into rooms (Elnahrawy et al., 2004).

2. Fingerprinting

A different technique for localization called fingerprinting uses in-advance mapped properties of the environment for position estimation. For example, the received signal strength of a WLAN signal is measured at as many different locations as possible within the target area. This information is saved including its spatial mapping. A sensor that wants to locate itself measures its current signal strength pattern and compares it to the pre-generated signal map. The closest match in the map is then assumed as the actual position.

The disadvantage of this method is the high initial effort that is caused by the mapping of the attributes of the environment. Consequently, this technique is not suited for unknown sites as there is no information available on the property used for the pattern matching. For this reason, fingerprinting does not comply to the requirements for the intended use case in mission-critical scenarios, because it requires a site-specific training and doesn't provide consistent results when structural changes happen in the environment. Tracking systems that use this technique can therefore be excluded from further consideration for the use in mission critical networking (Fuchs et al., 2011). However, combining fingerprinting methods with RSSI using machine learning AI (artificial intelligence) has the potential to yield good results.

Given our large training sets, it is unlikely that additional sampling will increase accuracy. Adding additional hardware and altering the model are the only alternatives. For example, ray-tracing models that account for walls and other obstacles have been employed. Pursuing the modelling strategy, however, we are left with a trade-off in model complexity vs. accuracy, and such questions are not easily answered. For example, it is unclear if building models at the level of detail where one must model all items impacting signal propagation (walls, large bookshelves, etc.) would be worth the improvements in localization accuracy (Elnahrawy et al., 2004; Schaubach et al., 1992).

Some of these localization methods are now used in commercially available solutions. With regards to the availability of technologies, two representatives from traditional manufacturers with long-term experience in the field were chosen for the purposes of our research.

3. Cisco Meraki

In the Meraki architecture, there is only one hardware component: the access points. All control, configuration, optimization, and mobility controls are centralized and delivered as service by the Meraki Cloud Controller (MCC) from Meraki's data centres. By eliminating separate controllers, and moving intelligence into the cloud, hosted wireless LANs reduce deployment time and complexity while enabling multi-site, scalable wireless LANs. In this configuration administrator logs into the controller system through web browser and provide access to wireless network of his account. All management is done remotely through a Web browser. The bottleneck due to centralized approach is avoided in case of Meraki Cloud Controller. Meraki's cloud-based architecture provides significant advantages over legacy hardware-based solutions. This configuration provides opportunity for cost reduction for WLAN management (Dalvi et al., 2011).

Cisco Meraki Access Points generate a presence signature from any WiFi-enabled device by detecting probe requests and 802.11 data frames from any device that is associated to the network. WiFi devices typically emit a probe request at regular intervals based on the device state. Smartphones send probe requests to discover surrounding wireless networks, so that they can make the networks available to the user. Meraki cloud aggregates raw client location data reported and provides a real-time estimate on the location of WiFi (associated and non-associated) and Bluetooth Low Energy (BLE) devices in real-time. The Scanning API delivers this data to your real-time location application, data warehouse, or business intelligence systems (Cisco Meraki, 2018).

4. Aruba central

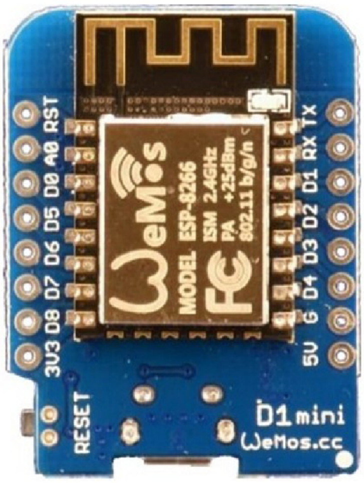
Aruba Central is a unified cloud-based network operations, assurance and security platform that simplifies the deployment, management, and optimization of wireless, wired and WAN environments. With continuous monitoring, AI-based analytics provide real-time visibility and insight into what is happening in the WiFi network. The insights utilize machine learning that leverage a growing pool of network data, and deep domain experience. The result is a consistent, reliable, and timely flow of information about the RF environment, that helps IT work smarter to deliver an optimal WiFi experience, despite increasing demands and the complexity that a growing network often brings. Presence Analytics offers a value added service for Instant AP based networks to get an insight into user presence and loyalty. The Presence Analytics dashboard allows you to view the presence of users at a specific site and the frequency of user visits at a given location or site. Using this data, you can make business decisions to improve customer engagement (HPE-Aruba, 2019).

5. WiFi client

The IoT device associated with a particular logistics element can be any electronics that is using WiFi or Bluetooth technology. Representatives of these technologies were chosen for the experiment: Bluetooth beacon EMBC01 (Subhan et al., 2019) (Figure 1) and the development module ESP-8266 (IEEE Electron Devices Society et al., 2019) (Figure 2).

Source: own processing

Figure 1: EMBC01.



Source: own processing

Figure 2: ESP-8266.

For the basic function of the ESP-8266 module, it was necessary to load the appropriate firmware into the processor. The following program (ESP8266 Community Forum, 2019) (Figure 3) was used:

```
const char* host = "host";
const uint16_t port = 17;
void setup() {
  Serial.begin(115200);
  Serial.print("Connecting to ");
  Serial.println(ssid);
  WiFi.mode(WIFI_STA);
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");}
  Serial.println("");
  Serial.println("WiFi connected");
  Serial.println("IP address: ");
  Serial.println(WiFi.localIP());}
void loop() {
  Serial.print("connecting to ");
  Serial.print(host);
  Serial.print(':');
  Serial.println(port);
  WiFiClient client;
  if (!client.connect(host, port)) {
    Serial.println("connection failed");
    delay(5000);
    return;}
  Serial.println("sending data to server");
  if (client.connected()) {client.println("hello from ESP8266");}
  unsigned long timeout = millis();
  while (client.available() == 0) {
    if (millis() - timeout > 5000) {
      Serial.println(">>> Client Timeout !");
      client.stop();
      delay(60000);
      return;}}
  Serial.println("receiving from remote server");
  while (client.available()) {
    char ch = static_cast<char>(client.read());
    Serial.print(ch);}
  Serial.println("closing connection");
  client.stop();
  delay(300000);}
```

Source: own processing

Figure 3: ESP-8266 source code.

6. Experimental method

The aim of the experiment is to verify the ability of WiFi systems to provide positional information even under restricted entry conditions. First, the layout of the AP was proposed. With respect to the floor plan in which the experiment was carried out and in combination with the limited possibility of connection to LAN infrastructure. The space selected and the limited number of APs did not allow optimal conditions to be achieved. The load-bearing parts of the building are made of reinforced concrete construction, the partitions separating individual rooms are built of burnt bricks.

The experiment focused only on associated devices. Two ESP8266 modules with WiFi were selected for the experiment. Within one measurement, the devices were always placed at a predefined location and subsequently a positional information query was sent. This measurement was repeated four times. This resulted in a sample of eight testing positions.

For the experiment, space was selected in only one part of the floor with the layout shown in Figure 4. The drawing is completed with coordinate rulers, the origin of the coordinate system is the upper left corner of the drawing of the entire floor. The APs were deployed according to Table 1.

Source: own processing

Figure 4: Test building plan.

AP position	AP1	AP2	AP3	AP4
X [m]	29.92	50.07	44.77	36.20
Y [m]	21.00	10.61	21.64	7.79

Source: own processing

Table 1: AP deployment coordinates

Results and discussion

Based on the experience gained in the experiment, we provide a comparison of HPE and CISCO systems in terms of quality parameters. Four operating parameters were chosen as criteria for evaluation of WiFi solution, considering (Perez-Castillo et al., 2018):

1. Security

From the security point of view, the solutions are very similar. The factor most significantly affecting security is the technological solution, where the configuration of the AP is carried out through the cloud platform, so any compromise of this platform can endanger the networks themselves. Both external access solutions provide a secure API.

The security of WiFi technology itself and its physical effect in the 2.4GHz band was for example elaborated by (Fernández et al., 2019).

2. Usability

Cisco Meraki is more usable, especially due to the complexity of the offered solution that works better with individual clients' location, providing approximate location information in the form of a geographic coordinate with a sufficient number of APs. The second solution is only able to provide information about presence / absence of an object.

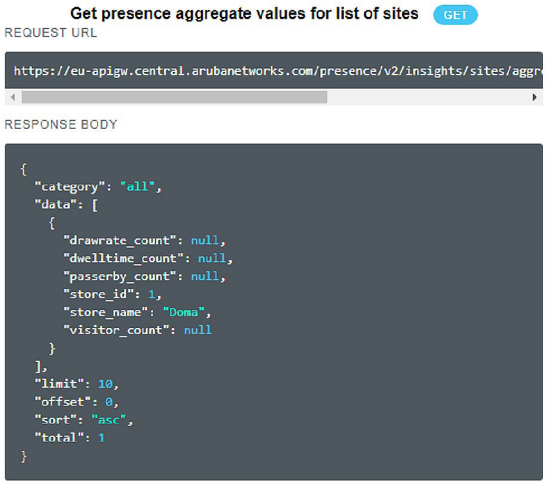
3. Sustainability

The sustainability of both solutions is very good, thanks to the cloud centralized message. In addition, Meraki's solution offers a better graphical representation of the location of each AP in the form of a map. And both the web portal and the API offer more configuration options.

4. Interoperability

The Meraki API is more extensive and provides more information. This makes it easier to connect this system to other systems. Important factor is also the format and complexity of the data itself. Data sources in the farm environment can be divided between the data acquired by the farm from its own internal, private data source and data obtained externally. External data can be used from public open data databases or purchased (Stočes et al., 2018).

An example of reading data from Aruba Central using the GET API is shown in Figure 5.



```
https://eu-apigw.central.arubanetworks.com/presence/v2/insights/sites/aggr
```

```
{
  "category": "all",
  "data": [
    {
      "drawrate_count": null,
      "dwelltime_count": null,
      "passerby_count": null,
      "store_id": 1,
      "store_name": "Doma",
      "visitor_count": null
    }
  ],
  "limit": 10,
  "offset": 0,
  "sort": "asc",
  "total": 1
}
```

Source: own processing

Figure 5: Aruba Central API.

The result of this experiment aimed at verifying the possibility of using commercially available APs to monitor the movement of the WiFi client is shown in Table 2. It shows the different locations of the WiFi client (blue and red dots in the plan) versus to which APs were associated.

Device	Position	A	B	C	D
Blue point	Meraki AP Presence info	AP1	AP3	AP4	AP2
	Aruba AP Presence info	AP1	AP2	AP2	AP2
Red point	Meraki AP Presence info	AP2	AP1	AP2	AP2
	Aruba AP Presence info	AP2	AP1	AP2	AP1

Source: own processing

Table 2: AP positioning experiment results.

These results show that Meraki AP was able to better determine the location of client devices. Both solutions provided a basic orientation about the movement of objects.

Conclusion

Even though the Aruba solution performed generally worse in our comparison, it offers sufficient functionality. The intention to monitor the movement of objects, especially in agricultural enterprises, was sufficiently addressed by both investigated solutions. However, we recommend choosing the CISCO Meraki solution. If there is already a WiFi solution installed within the agricultural enterprise, there should be no problem monitoring the movement of WiFi clients on other systems in a similar way as described in this article.

Any commonly used devices that communicate via WiFi, such as mobile phones, computers, sensors, etc., can be used as client devices. In the experiment, the development device ESP8266 (Syed Ali et al., 2016) was used, its added value is that it is possible to create a sensory / control device on this platform. All that at low cost of tens of dollars or so. Other possible devices that can be used are those with Bluetooth technology, especially Bluetooth beacon, which is primarily intended for these purposes. Even with its small size it can operate on batteries for a long time, at a low purchase price of about 5-10 $. For Bluetooth solutions however, it is necessary to have the appropriate infrastructure technology. Based on the research, it can be concluded that the currently available Wifi Systems can be used to monitor movement on the farm.

It is necessary securing the appropriate workforce for the task. If a subject does not employ the proper workers already, it is unfeasible to hire an entire team just for this task alone. Therefore, it is most efficient to hire the employees for a short time from a specialized agency or to outsource the whole project to a company that already has the required employees (Stočes et al., 2018).

It is commonly known that crop yield depends on crop growth variability, which is related to multiple factors that can be time-independent (e.g. substrate, topography, soil type and depth) or time-dependent. Annually linked factors may include anomalies in planting, emergence, or weather conditions. Seasonally linked factors can include plant diseases, weed development, severe climatic events, or irrigation system malfunctions (Bégué et al., 2008; Kumhálová and Matějková, 2017).

Another possible direction of research is the area of presenting the data obtained to employees of an agricultural enterprise. Alternatively, with the support of artificial intelligence, the data can be used to optimize logistics processes.

Another usage would be in BIM (building information modelling) which promises significantly advancing the architecture, engineering, and construction (AEC) market worldwide, however the low spread and adoption of BIM is still an issue. From a technology diffusion perspective, this paper proposes a game theory-based model including two firms who both are potential BIM adopters under support from the government (Yuan and Yang, 2020).

Application of this research can be, for example, monitoring of storage boxes and pallets, monitoring of machines and tools, employees, breeding animals such as cows, horses, etc.

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IoT and GIS data platform solutions in agricultural

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Abstract

The research is focused on the multidisciplinary process of converting data into useful information. For the applicability of research into a wide range of scientific and research projects, which are focused on obtaining physical information from the surrounding environment, new methods are used to obtain large amounts of data using battery-powered sensors. For example, to use data in the field of precision agriculture, or within the framework of the Smart Building and Smart City management and their resulting presentation to users in a clear and easy to understand form. All using Internet of Things (IoT) and Geographic Information Systems (GIS) technologies. For the overall processing of the resulting and functional whole it is essential to focus on the following sub-disciplines in two basic areas. The first area is IoT, which is mainly concerned with measurement and sensor technology, data transmission, data processing, statistics-Big Data and Artificial Intelligence. And in the second area (GIS), these are primarily tools for real-time data processing, additional data layers, tools for user interface (UI) and user testing when working with UI / UX. It is also important to monitor the economic impact and contact with potential partners, in which some parts of the research could be directly applied in practice. This study outlines, inter alia, possible partners, particularly in the agricultural sector.

Keywords [1]

IoT, GIS, Localization, Precision Agriculture, Smart City. Smart Building.

1. Introduction

This review study presents a research project that focuses on the complex issue of transferring information from the real world to the computer technology environment. Specifically, it is concerned with the intersection of two major technological areas, which are IoT (Internet of Things) and GIS (Geographic Information System). The intention may seem very simple at first glance, hovewer based on literature research and practical experience, it has been found that this is a very young field and thus many sub-topics are not addressed at all, especially those that have a multidisciplinary overlap. Alternatively, work in this area has been only recently produced. An example of such application of research, can be, for example, the localization of IoT end devices communicating within the LoRaWAN technology. The possibility of such localization was theoretically introduced at the beginning of the technology, as it is based on general physical assumptions. However, it is only now that the gradual deployment in practice shows that there are still many areas to be researched, such as the development of an algorithm for finding the optimal location of individual base stations (Gateway), considering the real physical environment, which is made up of rough terrain or buildings in the city, for example, by using GIS. Thus, the subject of the research itself is the elaboration of partial problems, hypotheses or questions. Some already known opportunities are listed under the chapter "Research Opportunities".

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Thus, the object of this review study is to introduce the concept shown in **Figure 1**, which demonstrates the simple concept in an illustrative way. Where a sensor device located in a mountainous area measures the quality and condition of the water in a stream, the data is processed in real time in an automated analytical manner and the operator receives only the required information, completely accurate and already statistically processed.

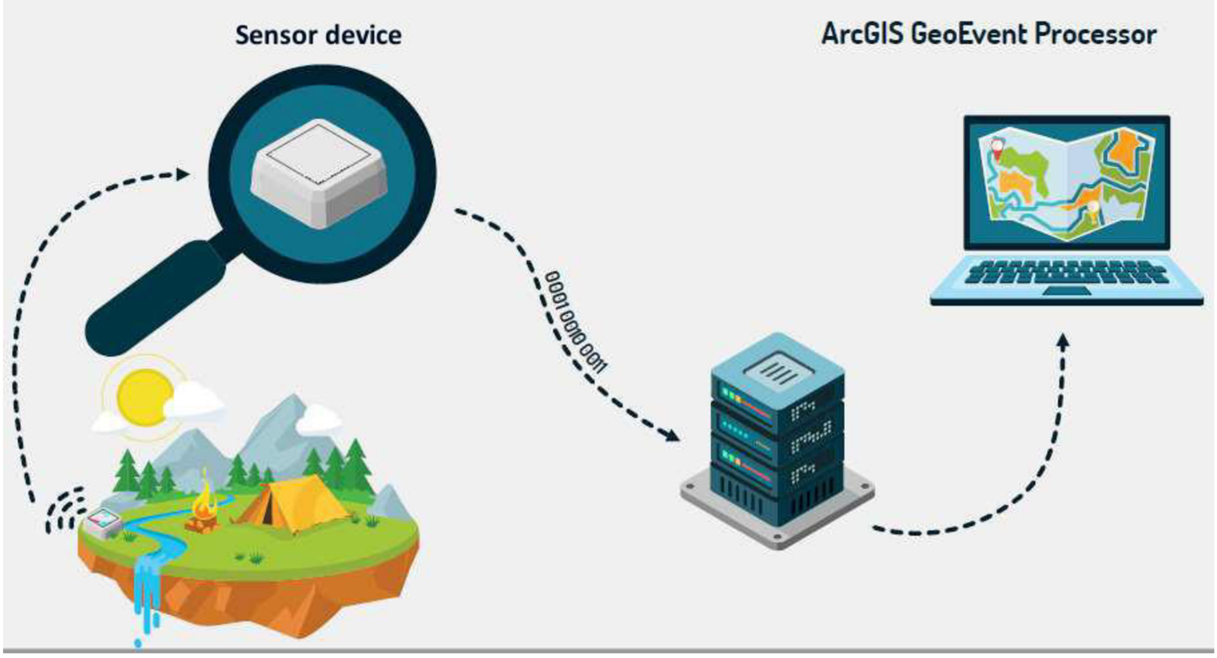


Figure 1: Conteptual scheme of the intent

2. GIS Environment

It seems, that ESRI software is suitable option in GIS area. Thanks to its long history, in 1969, Jack Dangermond—a member of the Harvard Lab—and his wife Laura founded Environmental Systems Research Institute, Inc. (Esri). The consulting firm applied computer mapping and spatial analysis to help land use planners and land resource managers make informed decisions. The company's early work demonstrated the value of GIS for problem solving. Esri went on to develop many of the GIS mapping and spatial analysis methods now in use. These results generated a wider interest in the company's software tools and work-flows that are now standard to GIS.[1]

2.1. ESRI GIS platform data sources

ArcGIS GeoEvent Server stores and processes geospatial data in real time. It also provides tools for online import of IoT sensor data. Using defined filters and detailed selections, data can be drilled down to focus on a specific problem. The GeoEvent server automatically updates maps and databases, allows alerts to be sent when threshold are met or an event occurs. GeoEvent server allows dynamic data to be linked to the entire ArcGIS system. For example, the Operations Dashboard is an application that is fully suited to receive real-time data. [2–5]

The Collector for ArcGIS is also part of the Geospatial Cloud platform. Mobile apps are an effective tool for use in the fieldwork. Users can add, edit, and describe elements on the spot and data is automatically uploaded to the server for other users or for subsequent analysis. The app supports offline mode using downloaded maps on the phone. The app is currently supported on Android and iOS mobile platforms. [6,7]

ArcGIS Notebooks provide users with a Jupyter notebook environment, hosted in your ArcGIS Enterprise portal and powered by the new ArcGIS Notebook Server. Because it works with the Docker container allocation technology to deliver a separate container for each notebook author, it requires specific installation steps to get up and running. Once you've installed ArcGIS Notebook Server and configured it with your portal, you can create custom roles to grant notebook privileges to the members of your organization so that they can create and edit notebooks.[8]

2.2. ESRI GIS analysis tools

Spatial analysis is a complex part of working with the data. It includes visual analysis of maps and imagery, computational analysis of geographic patterns, finding optimal routes, site selection or advanced predictive modelling. Analysis uses data from all kinds of technologies – GPS, IoT sensors, social media, mobile devices, satellite imagery and many more. Geographic information systems use functional tools, such as QGIS, ArcGIS Desktop or ArcGIS Pro.[9,10]

"ArcGIS can analyse data, locate a site according to specified criteria, optimize vehicle routes and perform advanced predictive modelling. In a user-friendly and interactive map, one can view, for example, the intensity of a phenomenon in selected areas, branch revenues in individual periods or, even data about customers in the context of the general demographics of the area and the collected data about competitors. Many companies and government organizations use ArcGIS tools to plan their investments." [11,12]

2.3. ESRI GIS visualization tools

Visualizations may include maps, graphs, statistics and cartograms that show, for example historical changes and current developments. The importance is given on clarity and accuracy. For the users themselves, ease of use is essential, which is satisfied, for example, by following ESRI programs:

The operations Dashboard application (**Figure 2**) is designed to create thin clients. In addition to the features common for web map applications, it also includes tools specialized for continuously changing data tracking. The application accesses individual data as well as map layers and uses a user interface (UI) to guide the user through the creation of individual operational views. User can create the views themselves through the individual tools. These tools can be a map, a table, a graph, or others. [13]

Figure 2: Operations dashboard application screenshot

ArcGIS Earth is an easy-to-use lightweight client for 3D data visualization. By viewing data in a spatial context, it lets us see features that are not well represented on a conventional map. Therefore, we can upload data in KML, shapefile and various other web layers and explore their interrelationships.[14]

Web AppBuilder for ArcGIS is intuitive what-you-see-is-what-you-get (WYSIWYG) application that allows to create 2D or 3D web application without typing a single line of programming code. It also includes powerful tools for configuring fully functional HTML.[15–17]

Story maps are a combination of maps, text, images and multimedia content. They facilitate the use of the power of maps and geography to tell a story.[18]

3. Data transmission

3.1. LoRaWAN technological area

Open specification LoRaWAN is a low-power, broadband network protocol (LPWAN) based on LoRa technology. The LoRaWAN protocol is designed for wireless connection of battery-powered devices in regional, national or global networks, using unlicensed radio spectrum in Industrial, Scientific and Medical (ISM) band. Its architecture is shown in **Figure 3**. LoRa defines the lower physical layer, whereas LoRaWAN provides upper networking layers, this provides seamless interoperability between devices. While Semtech provides radio chips with LoRa technology, the LoRa Alliance®, a non-profit association and fastest growing technology alliance, is driving the standardization and global harmonization of the LoRaWAN protocol [19–22]

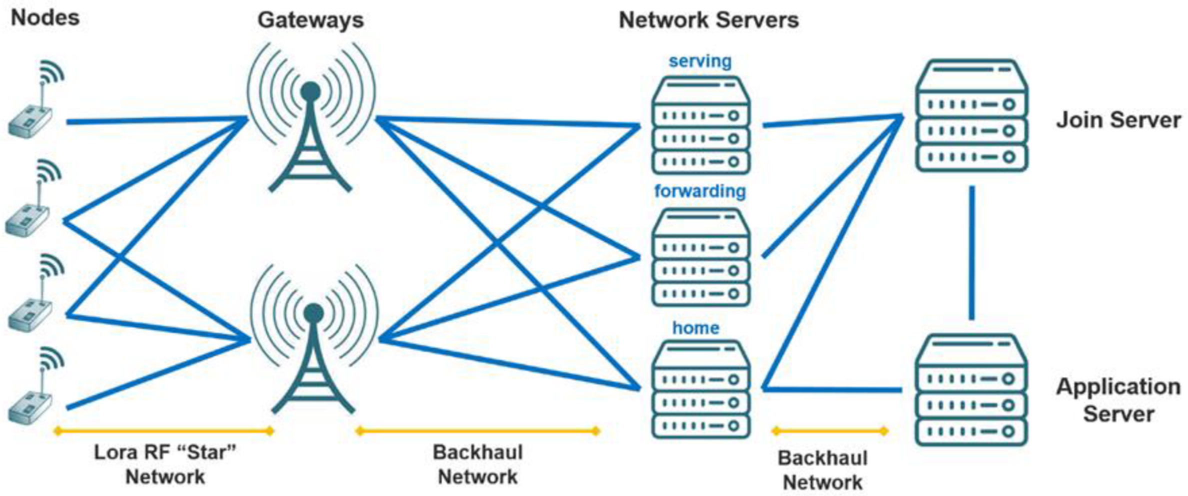


Figure 3: LoRaWAN network architecture [23]

3.2. LTE-NB and LTE-M technology area

Within the technologies that are provided as "classic mobile", the IoT area can also include LTE-M and LTE-NB technologies. These are very similar technologies, that are designed for communication between battery-powered devices. The difference between these technologies is explained in the following example found in the next paragraph. [24–26]

Automotive systems nowadays come typically with integrated connectivity to the internet, making it possible to present up-to-date traffic information or send diagnostic information to the manufacturer to analyse the behaviour of internal systems. When the device is in operational mode, in most cases, there is sufficient power to allow the user to be online with the current mobile operator connection. However, the vehicle needs to be "online", i.e. connected to the Internet even when the vehicle is parked. This creates a new requirement for a completely different behavior of energy requirements than in normal operation. LTE-M is the solution for all scenarios with moving transmitters. Another possible type of devices in the network are small stationary sensors that monitor physical quantities, such as temperature, humidity, air pollution, flow rate, etc. These simple sensors are usually battery powered and have to make do with a minimal data transmission for their operation. The end devices need a minimum amount of energy to transmit information about changes in their status so that they are able to perform their function for several years. LTE-NB technology is used for similar devices.[27]

4. IoT location tools

4.1. General localization methods – RSSI, TDoA

The RSSI value has been considered as a metric in most distance measurement algorithms. Although the inefficiency of RSSI is mentioned in the literature, not many attemps have been made to implement it in practice. Elnahrawy and colleagues explored the idea of using RSSI in location algorithms carried out in indoor environments and found that for improve the accuracy of RSSI-based methods when used indoors, more sophisticated models and algorithms are needed. The use of artificial intelligence and machine learning has great potential for better use of the RSSI method. [28-30]

TdoA is another technique where nodes are localized using 3 or more base stations with precise time references obtained from the GPS signal. The method is particularly applicable to the technology of LoRaWAN. The method is illustrated in **Figure 4**.[31,32]

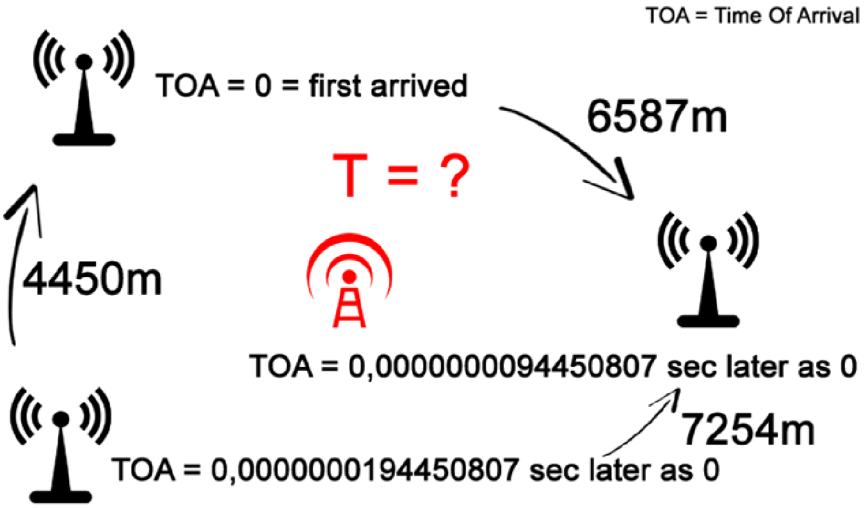


Figure 4: TDoA principle [33]

4.2. Wifi and Bluetooth systems

Some of these location methods are already used in commercial solutions available nowadays. Given the availability of the technologies, two representatives from traditional manufacturers were chosen, both with many years of experience in wired or wireless computer networks.

Cisco Meraki Access Points (Aps) generate information about the presence of any Wi-fi enabled device by detecting AP requests from unconnected devices and 802.11 data frames when the device is connected to the network. Wifi devices typically issue AP request at regular intervals based on the status of the device. Smartphones send probe request to discover nearby wireless networks in order to make the networks available to the user. Cloud Meraki aggregates raw client location data and provides a real-time estimate of the location of Wi-Fi devices (associated and non-associated) and Bluetooth Low Energy devices (BLE) in real time. A Scanning API is also available that allows data to be delivered to a user application, data warehouse or business intelligence systems, all in real time. [34–36]

Some research makes use of this, for example [37,38]

4.3. Data flow processing – Node-RED

The Node-RED application can be run on virtually any computer.
Node-RED is an Internet of Things (IoT) programming tool that connects hardware devices, APIs, and online services. It provides a browser-based editor that allows you to easily link data streams using a variety of nodes. Only the interpretation of the code precedes the start of the application.

It is therefore visual flow-based programming and thanks to its simplicity and clarity allows users to quickly create applications using a simple drag-and-drop interface.
Node-RED is built on Node.js®, so it is an "agnostic platform." It runs as easily in the cloud as on the Raspberry PI. With more than 600 community features available to expand the range of features. An active community moves the whole project forward.

5. Practical

The practical section presents several ways in which data can be loaded into the ArcGIS platform. First, the actual data message displaying the information retrieved from the device is presented. This data message is the same for all three options regarding the loading of sensory data into the ArcGIS platform. The first option is the possibility of connecting ArcGIS to a PostgreSQL database, the second is the possibility of using Python script and the last option presented is the use of ArcGIS GeoEvent Server.

5.1. Sensor data structure

Sensor data constists of the values of individual sensors and the corresponding metadata. In addition to the identification of the device and the individual sensor, location information is also included within the data structure. This information is obtained by RSSI or TDoA method using LoRaWAN technology. The position information is important for further data processing withing the geographical information system itself.

```
{
    "deviceIdentificator": "JO-TEST-ASMkN0zRWJr0",
    "deviceModel": "E1-SBLX/AVBX-AVBX",
    "measurements": [
        {
            "time": "2021-09-03T08:18:12Z",
            "quantities": [
                {
                    "key": "dev_temperature",
                    "value": 25.61,
                    "unit": "°C",
                    "min": -40,
                    "max": 85,
                    "decimal": 2,
                    "name": "nazev",
                    "adr": "I.1"
                }
            ],
            "position": {
                "altitude": 999,
                "lat": 50.0908992,
                "lon": 14.4006189,
                "positionAccuracy": 18,
                "positionDiff": 0,
                "speed": 0,
                "source": "LWR",
                "EPSG": 3857,
                "format": "(D+[.d*])"
            },
            "networkParam": {
                "nType": "LoRaWAN",
                "provider": "CRA",
                "data": {↔}
            }
        }
    ]
}
```

Figure 5: Data structure

5.2. Node-RED

The first presented method of transferring data to the ArcGIS platform is to store the measured data in a database and the connect this database as a data layer. The following figure shows a visualization of the code in the Node-Red application that is storing the data in the database.

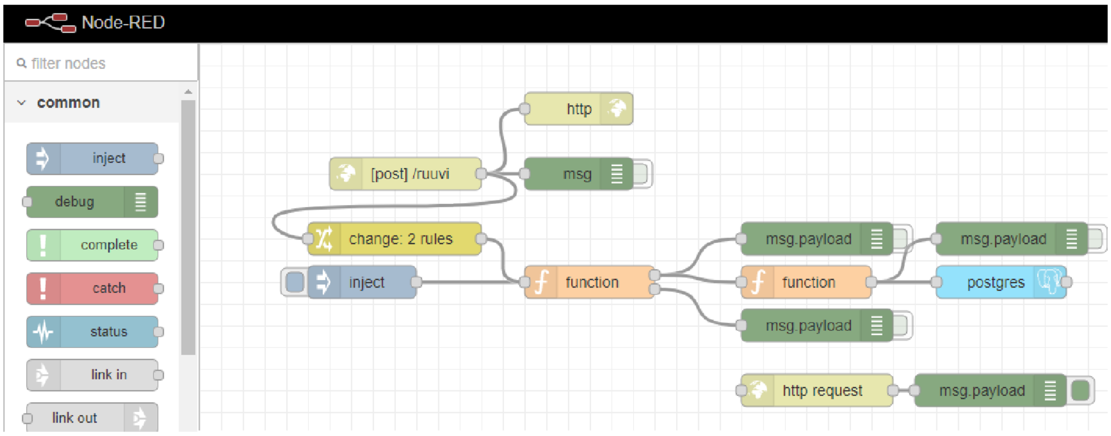
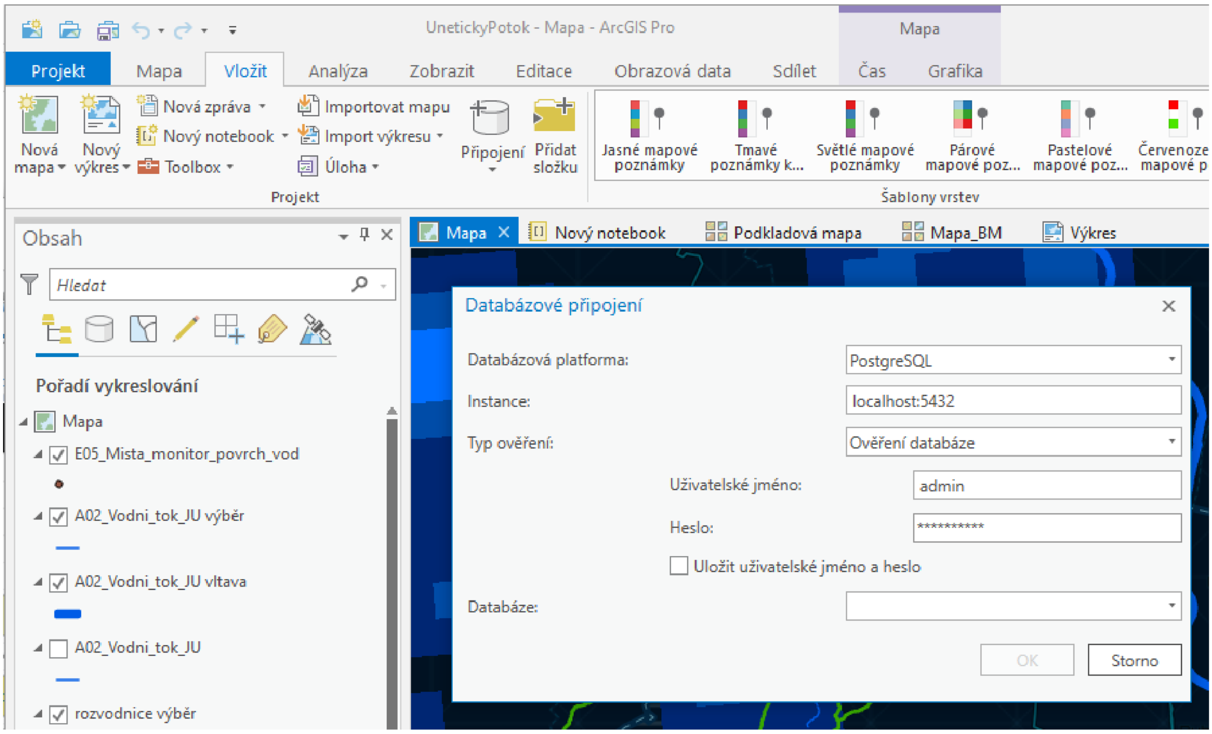


Figure 6: Node-RED application

In the **Figure 7** it is possible to see an example of how to the data can be inserted into the different geographical layers after connecting the database.



Databázové připojení

Databázová platforma: PostgreSQL

Instance: localhost:5432

Typ ověření: Ověření databáze

Uživatelské jméno: admin

Heslo: **********

☐ Uložit uživatelské jméno a heslo

Databáze:

Figure 7: Arc-GIS Pro database connection

This solution requires the use of other applications in addition to the ArcGIS platform itself, making the entire solution complicated and more difficult to maintain and extend. For example, user and application permissions must be handled separately in several places. The following two examples focus only on direct use of the ArcGIS platform.

5.3. Python script

The Python scripting language support built into the ArcGIS platform provides an ideal solution for data transformation and analysis. With libraries, the script can access services within ArcGIS online and ArcGIS enterprise. The following **Figure 8** shows a script for loading, editing and publishing data within the ArcGIS platform.

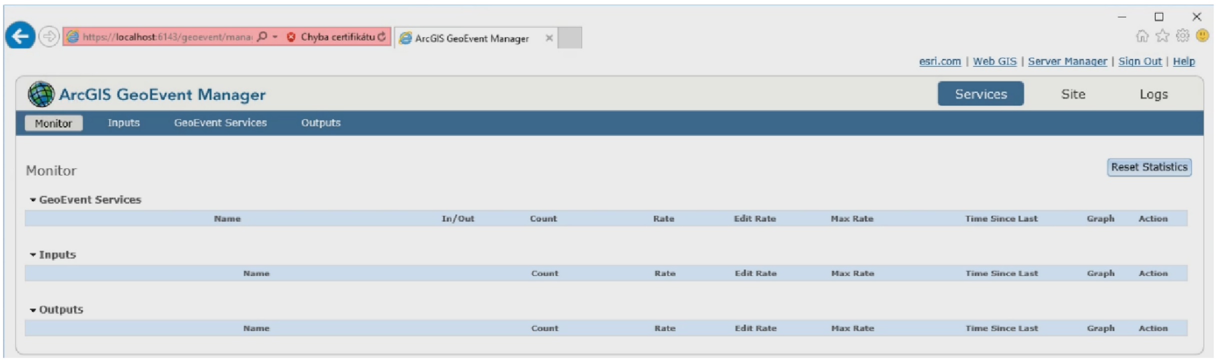
```
In [1]: from arcgis.gis import GIS
        import pandas as pd
        import requests
        import json
        import csv

        def fetch_api_data(url):
            session = requests.Session()
            session.headers.update({"Content-Type": "application/json"})
            response = session.get(url)
            data = json.loads(session.get(url).content.decode("utf-8"))

            timestamp_modified = pd.Timestamp(data["modified"], tz="Europe/Prague").tz_convert("UTC")


            df = pd.DataFrame(data["data"])
            column_names = {"id":"deviceIdentificator","key": "key", "value": "value","unit": "unit",
                            "min": "min", "max":"max", "time": "time", "lat":"lat", "lon":"lon"}

            df = (
                df
                .rename(columns=column_names)
                .assign(date=lambda x: pd.to_datetime(x["time"], format="%Y-%m-%d").dt.tz_localize("UTC"))
                .assign(id=lambda x: x ["time"].dt.strftime("%Y-%m-%d")+ id)
                .assign(modified=lambda x: timestamp_modified) .sort_values(by=["time"])
                ---
                ---
                ---
                )
            output_columns = ["id","time", "key", "value", "unit", "min", "max","lat","lon"]
            print(df)

            ---

            # Let us publish service
            service_item = gis.content.create_service(name='IoT_data', service_type='featureService')

            ---
```

Figure 8: Python script

The advantage of this solution is considerable flexibility and simplicity of implementation. The disadvantage may be the necessity of knowledge of the Python environment and individual ArcGIS libraries. In contrast, the following solutions using ArcGIS GeoEvent Server offers an ideal and robust solution for all GIS users, as this solution is not primarily coded but configured, unlike the previous examples.

5.4. GeoEvent server

The following **Figure 9** shows the portal in which the complete configuration of this extension takes place. In function, it is similar to the Node-RED application, but is ready for scalable, robust and long-term operation.



Monitor

▾ GeoEvent Services

Name	In/Out	Count	Rate	Edit Rate	Max Rate	Time Since Last	Graph	Action

▾ Inputs

Name	Count	Rate	Edit Rate	Max Rate	Time Since Last	Graph	Action

▾ Outputs

Name	Count	Rate	Edit Rate	Max Rate	Time Since Last	Graph	Action

Figure 9: GeoEvent dashboard screenshot

On the "Inputs" page, see **Figure 10**, it is possible to set any commonly used interface. From IoT perspective, it is necessary to choose protocols that allow real-time communication. For example, WebSocket communication containing data in JSON format is suitable choice that meets this requirement. An alternative option is, for example, the MQTT protocol. Outputs are set up in a similar way, on the "Outputs" tab.

Receive GeoJSON on a WebSocket

Receives GeoJSON over a WebSocket and converts it to GeoEvents.

Receive JSON on a REST Endpoint

Receives generic JSON on a REST endpoint and converts it to GeoEvents.

Receive JSON on a WebSocket

Receives generic JSON over a WebSocket and converts it to GeoEvents.

Receive RSS

Receives an RSS or ATOM feed and converts it to GeoEvents by polling a URL at a fixed frequency.

Figure 10: GeoEvent input connectors screenshot

The executive parts of this add-on are the functions in **Figure 11** (marked in yellow), which allow to perform arbitrary operations on the data. The basic functions are already prepared. If necessary, there is an SDK in Java programming language, which can be used to create a custom functions. After setting up the inputs and outputs, which are shown in **Figure 11** (marked in green and blue), everything can be interconnected.

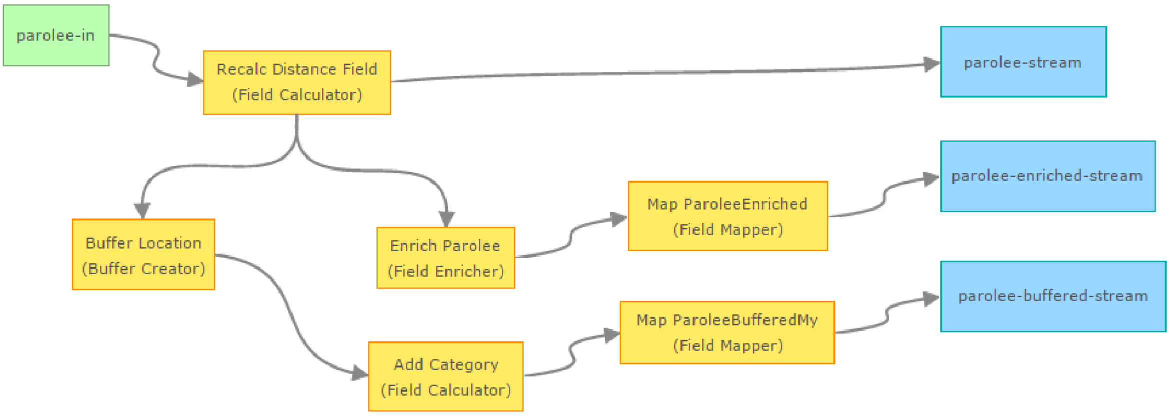


Figure 11: Operations dashboard application screenshot

6. Economic and commercial overlap

Insights from practice can lead to to new research questions and, in turn, research results can be positively evaluated financially, thus supporting further research. Thus, mutual collaboration and exchange of experience/know-how can lead to workable and useful solutions.

6.1. Floods protection - focus

Based on the reviewers' recommendations, I present an example of a possible scientific and commercial application of the above methodology, combining IoT and GIS technologies. This example is an insight into already prepared publications devoted to the research plan of cooperating sensors coordinated by a geographic information system.

A specific example is shown in Figure 12, where the left part shows a model replicating a real environment involving precipitation. The slope and water absorption of the terrain and the system of watercourses. These rivers are monitored by a network of IoT sensors (shown on the right). These sensors provide, for example, real-time level data. Thanks to the knowledge of their location within the model, it is possible to better predict the development of the situation and thus not only ensure the protection of property, but also optimize the operation of the sensors themselves.

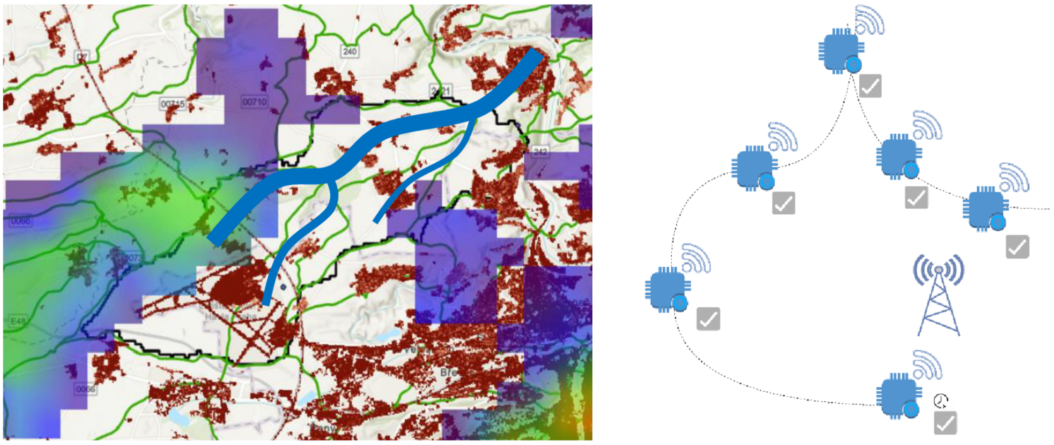


Figure 12: practical connection of GIS and IoT

Next research opportunity

The intention of the research is to address partial research within the complicated process from measurement of data and its wireless transmission using LPWAN technologies, especially in order to save energy of the sensor device itself. Furthermore, verification of their quality and credibility, after obtaining valuable information and its subsequent use, either for further research or direct presentation, using geographic information systems.

For data processing in geographic information systems, it is desirable to add location information or information about the time of the event to their data. For this purpose, it is also necessary to address the area of location information extraction.

From the point of view of the potential application of this research, it is also important to ask about possible practical application or business and economic benefits. For this reason, it is seen as important to be in contact with potential end-users or intermediaries as a part of the research using the results of the research and to support the possible transfer of technology and knowledge from research into practice.

Specific sub-research opportunities may be, for example:

- Verification research to compare the quality and usability of available HW for IoT technologies.
- Use of Big Data and AI analytics for IoT Data Quality Control. In particular, accuracy and calibration of sensors. In the context of data processing with traditional statistical methods, it is necessary to ensure the "purity and uniformity" of the measured data. It is questionable whether new approaches are not able to eliminate this necessity, and example would be trend tracking, for which it is not necessary to know the absolute values.
- Research on technology for analyzing anomalous behavior of IoT sensors in the GIS environment, especially the use of Big Data and machine learning.
- A very specific technological problem is to ensure the decoding of the data message sent by the device, especially in LPWAN networks. Current systems and solutions are very heterogeneous and unsustainable in the long term. The essence of the problem is the necessity to minimize the volume of data send by the device and the desire to transmit as much information as possible for cloud processing.
- Research on methods for low-power positioning using GPS.
- Obtaining the maximum possible information using metadata from the operation of Wifi technology
- Finding the optimal placement of localization devices (AP/GW) to increase localization accuracy. For RSSI and TDoA methods.
- Research withing the Human Behavioural Research Unit (HUBRU) to find out the general public's ability to receive information presented in the form of a map. For example, whether the form of graphs and tables is perceived better than coloured shapes on a map.

7. Conclusion

Significant differences can be observed within the presented methods for loading data into the ArcGIS platform. For each project, the most appropriate approach needs to be selected, taking into account the circumstances. Presented tools and methods are certainly applicable in scientific research.

This review study introduced many topics, that have been scientifically investigated to some extent by partial research in particular areas. However, we were not able to find any such comprehensive work that has addressed this fundamentally new issue in such a context and scope. We are convinced that a comprehensive view of this issue may provide new opportunities and insights.

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6 Závěr

Prezentované výsledky v jednotlivých výzkumných oblastech potvrzují předpoklad, že aplikací inovativních metod v oblasti IoT lze dosáhnout optimalizace provozu senzorických řešení s bezdrátovým přenosem dat a jejich zpracování v rámci Geografického informačního systému.

6.1 Splnění dílčích cílů disertační práce

Hlavním cílem této práce bylo navrhnout metody a doporučení optimalizující provoz IoT sítí senzorů pro potřeby geografických informačních systémů a řešit tak technická či ekonomická omezení znemožňující uplatnění těchto nových systémů v praxi. Zejména pak se zaměřením na zajištění dostatku elektrické energie pro spolehlivý a dlouhodobý chod zařízení.

Zcela unikátní výsledky poskytlo experimentální vyhodnocení dostupnosti LoRaWAN kanálů v rámci provozu senzorického zařízení, u kterých při aplikaci zjištěných poznatků lze zvýšit úspěšnost doručení senzorické zprávy. Výsledky byly publikovány v časopise Sensors s IF 3.847. Další publikované výsledky poukazují na možné technické a ekonomické přínosy.

I ostatní výsledky v páté kapitole dokladují naplnění hlavního i dílčích cílů práce.

Výsledků bylo dosaženo zejména za využití vědeckých laboratoří PEF, zejména pak laboratoře internetu věcí (IoT) a laboratoře Geografických informačních systémů. Dále bylo využito podpory od komerčních společností.

6.2 Přínosy disertační práce pro vědu a praxi

Dílčí výsledky byli uplatněny v rámci projektů, jenž byly grantově podpořeny. Tedy práce byla realizována v kontextu již probíhajících výzkumů, a to díky nezávislosti studované problematiky na konkrétním aplikačním prostředím. Čímž také byla ověřena zobecnitelnost výsledků pro další vědecký výzkum.

Výsledky také byli aplikovány v projektech realizovaných katedrou, zejména pak v projektu „Life Scicence 4.0“ a nyní jsou uplatňovány v projektu „datové platformy ČZU“ budoucí výsledky lze v rámci univerzity uplatnit v projektech typu Chytrá krajina Amálie nebo Smart Digital Campus.

Dále výzkum podpořila městská část Praha-Suchdol, která umožnila instalaci senzorického zařízení nad Únětickým potokem a poskytla komentáře jakožto uživatel technologického řešení. Bylo tak dosaženo i aplikace získaných výsledků v praxi.

6.3 Diskuse a náměty k dalšímu výzkume

Práce otevírá myšlenku uceleného pohledu na kompletní řešení od požadavků uživatelů, přeš senzorická zařízení s konkrétní geografickou polohou, bezdrátový přenos dat až po informační systémy pro podporu rozhodování. To vše jako jeden systém složený z dílčích spolupracujících systémů.

Potenciál dalšího výzkumu potvrdil Alessandro Pozzebon Ph.D. z Italské Padovy, kde v rámci zahraniční spolupráce budou dlouhodobě probíhat dílčí vědecké experimenty pro ještě lepší porozumění jednotlivým parametrům a vazbám v systémech za účelem vytvoření detailního modelu jednotlivých výše zmíněných systémů. Tedy podařilo se zahájit mezinárodní vědeckou spolupráci.

Konkrétním námětem na další výzkum je primárně rozvoj zaměřený na implementaci nových technologií aktuálně zejména v oblasti přenosu dat. Například technologií označovaných jako „sítě 5. generace (5G)“.

Současné i budoucí výsledky případných návazných výzkumů jsou široce uplatnitelné kdekoli v obdobných projektech a je tak široký prostor pro aplikaci poznatků do dalších výzkumů.

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8 **Příloha č.1** - Další publikační a jiná činnost autora

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