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Opportunities and challenges for real-time management (RTM) in extensive livestock systems

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Abstract

Extensive livestock systems face many challenges associated with their environment. They are often associated with poor quality grazing, harsh weather conditions, few or no fences and do not allow for frequent inspections of animals. In addition, the availability of appropriately skilled labour is becoming short in supply. PLF technology promises the capability to transform these systems. Four technologies are evaluated through case studies related to practical deployment and some research results. (1) LoRaWAN (Long Range Wide Area Network) often referred to as LoRa, which is an enabling, IoT, technology communicating, in this case, from animal-wearable sensors, via cloud-based computing to end-users. A network involving two LoRa gateways was established linking on-animal sensors to the 'cloud' and thence to management information. (2) GNSS - location data were collected from collars and communicated, via LoRa, to determine data transfer efficiency and location accuracy. (3) Proximity sensors - small proximity beacons on lambs and receivers with LoRA transmitters on their collared dams to assess lamb-dam pedigree information. (4) Tri-axial inertia movement units (IMU) - IMU data was communicated in real-time via LoRa enabled transmitting neck collars. The range of wearable technology provided reliable and potentially useful management information. Combined technologies provide the best technical promise but all four technologies have particular challenges in terms of costs and benefits in these extensive systems.

Keywords: real-time monitoring, extensive, LoRA, IMU, GNSS, proximity

Introduction

Real time monitoring (RTM), involving stockpeople using their eyes, ears and noses to assess the state of livestock is as old as domestication. New technology to collect data on animal behaviour and location typically involved storing data on the animal device. A shift from collecting past data to RTM now enables greater use in practical management within livestock systems.

In extensive systems, approaches to communication between devices and user through either copper wire systems or wi-fi based systems, do not work. The mobile phone network can be very effective but also has many issues of communication. The other major challenge is cost–effectiveness. In many intensive systems, individual animals have high value, or there are large concentrations of animals in the same location and opportunities for technology to improve animal output, reduce losses and save labour are frequently reported (e.g. Halachmi, 2019). These applications may involve individual wearable technology or fixed equipment in facilities with large concentrations. In extensive systems, by contrast, animals tend to be of lower value, are often widely dispersed, and typically have much lower stockperson contact. The cases for both technical effectiveness and cost/effectiveness are thus very different in extensive systems.

LoRa is fast becoming one of the key elements of the IoT revolution (Carvalho Silva *et al*., 2017). As a low power, long range, wireless telecommunication network, it is well suited to extensively farmed environments as gateways receive data packets from LoRa devices located within ranges typically over 20 km line-of-sight radius in rural areas and then forward the data packets to a network server (Pharm *et al*., 2017). A single gateway can receive data from thousands of sensors. With significant promotion through cross-industry partners (e.g. LoRa Alliance) and a business model that uses license-free sub-gigahertz radio frequency bands, with network-costs embedded within the devices, it has the potential to benefit farming in the future.

GPS/GNSS is now a mature technology, but continues to develop to make it better suited for on-animal deployment in terms of spatial resolution, power requirement and cost. There are a number of businesses aiming to combine LoRa with GNSS to provide real-time monitoring for livestock. It is also feasible to obtain additional information across the LoRa network such as ‘proximity’ information through device-to-device communication using RFID technology, Bluetooth or NFC (near-field communication). Bluetooth technology has also been proposed to identify ewe-lamb connections (Sohi *et al*., 2017). Already commercial equipment and services are available to utilise this approach (e.g. SmartShepherd, www.smartshepherd.com.au/).

In this paper, we will provide some case-study experiences of four different technologies under testing for extensive system applications. This will give an insight into some of the issues involved in their development and application into practice, and their potential value in extensive sheep and beef systems. We will cover LoRa as an enabling communication method, and then some work with GNSS, proximity sensors and motion sensors. Specifically, we will highlight some of the benefits and constraints of real-time communication with LoRaWAN.

Material and methods

LORAWAN communication and study site

Two LoRa gateways were deployed with some overlapping coverage. Each was connected to the internet via an ethernet connection. Data was automatically uploaded to TheThingsNetwork server (www.thethingsnetwork.org) and data provided as data downloads. Visualisations to an app was also available for some of application case studies described. Figure 1 shows an illustration of a system connecting on-animal wearable technology with the farmer. LoRa provides the communication route for the GNSS data and any other on-animal sensor data. In our case studies, this involved both proximity data and IMU data.

The topgraphy and location of the study site (Kirkton Farm, Crianlarich, Scotland) was very challenging for LoRa. The three sheep studies described were undertaken within grazing fields and larger paddocks on rolling terrain with, or surrounded by, hillocky land. ‘Line of sight’ to either of the two aerials was not possible from many locations within the study fields due to this topography.

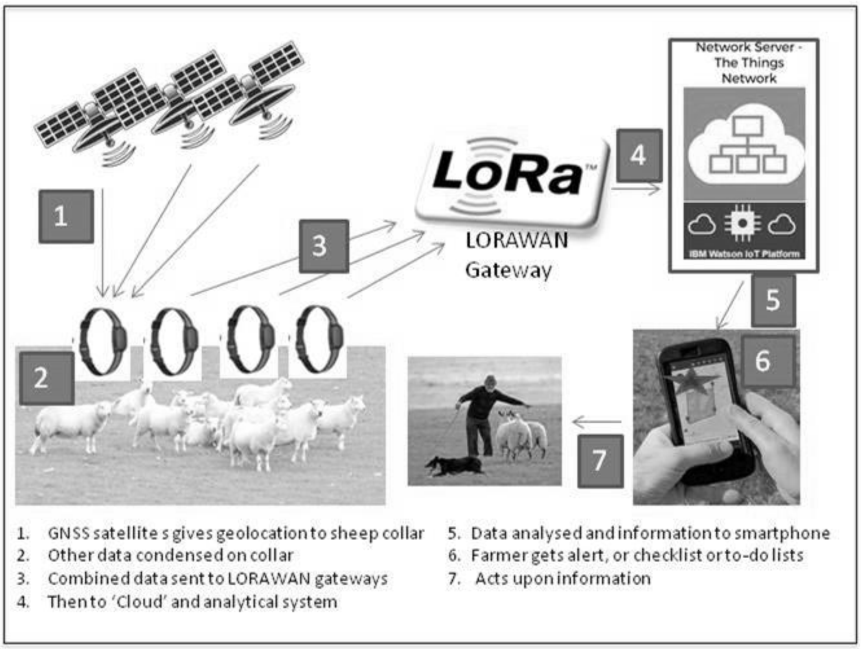

Figure 1: The Communication pathway – from sensors on animals back to the stockperson

GNSS

Sheep study A involved prototype sheep collars (containing GNSS technology and communicating via LoRa) that were placed on two non pregnant ewes within a flock of 12 ewes in a small field (1.85 ha) referred to in the Results section as the target field. The field centre was 625 m from the nearest LoRa gateway. The field was not in the optimum 'line of sight' for the LoRa antennae, with some buildings and topography creating potential barriers. The two collars were configured to require a minimum of six GNSS satellites for location triangulation with data transmission frequency set to either one or five minute intervals over a 14-day period. Prior to deployment, the '1 minute' collar was placed on the top of each corner fencepost for a minimum period of 60 minutes.

Sheep study B involved other prototype collars with combined GNSS technology (locating 8 satellites before a fix) and 3 sets of tri-axial motion sensors. In this case the centre of the field was c 250 m from the nearest LoRa gateway antennae, with much of the field, including some narrow ravines, with no direct line of sight to either of the two gateways. Data were collected from 5 sheep amongst a small flock for 32 days.

Proximity

Sheep study C involved data collected from a small flock of 20 Scottish Blackface ewes and their lambs (n = 40). Collars were fitted to eight of the ewes and eighteen lambs over a three-week period. Each ewe collar had a printed circuit board with a Bluetooth proximity sensor and a LoRa communication module set to communicate every hour. Each lamb had a small collar with a proximity beacon. Firmware on the ewe collar identified the five closest lamb beacons over the hour period and communicated the identity of these beacons, together with the accumulated Received Signal Strength Indication (RSSI, a measure of signal strength) for each beacon, over each deployment.

Motion Sensors

This element of research was conducted alongside the GNSS study B above. The five collars incorporated both GNSS and a set of three tri-axial motion sensors. Data were recorded at 10 Hz for each of the axis, the magnitude of the vectors were computed after preliminary groundtruthing of specific behaviours of interest (grazing, lying, walking), were then mapped to the magnitude outputs. The condensed data were then sent through LoRa as a set of 11 indices every 2 minutes. Whilst some 'ground-truthing' behavioural observations were conducted, this element of the study is not described in this paper, here we focus on the simple feasibility of communicating a number of condensed elements of the very large sets of initial IMU data.

Results and Discussion

The most fundamental technical need for the LoRa element is to be able to communicate data, without or with, manageable error. Figure 2 shows data communication intervals for two sheep collars, set with a 2 minute interval. As noted above, these sheep were in the same grazing area, but within a very hillocky paddock with less than perfect line-of-sight between sheep locations and either LoRa gateway antennae. The pattern of communications shows that 95% of upload of data packets from collar to network server were within 2 minutes +/- 10sec, with subsequent pick up of data at each 2 minute interval with the residual number of lack of data packet transfers halving at each 2 minute period. The near perfect alignment between the two collars (the other three collars had near identical patterns) illustrates that very little of the communication drop off is likely to be due to within-field issues caused by differences in sheep location, but more likely performance issues with the GNSS not registering the minimum number of satellites. Longer gaps in transmissions were likely to be due to breaks in communication between the gateway and network server affecting all collar data sets equally. One clear issue with real-time data transmission illustrated here is that data collected and collated on the collar during each programmed duty cycle is lost if it is not received by a gateway or if the gateway to network server connection is down. The collar/LoRa just moves on and sends the next duty cycle of data.

The spread of mapped points from the collars in Study A at static points were in excess of 20 m (10 m radius from the centre), as a result of standard GNSS error. Many sheep location 'hotspots' linked to both grazing and camping areas for the two collared sheep were in close proximity to the fence line with a high proportion of locations on the outside of the fenceline and simplistically these would be allocated to another field rather than the target field. As shown in Table 1, for Sheep 1, with 15,976 locations at 1 minute location cycles over 14 days, it was found that 29% of locations were outside the best assessment of the fence line boundary. Stepwise combinations of rolling average and a 10 m buffer zone reduced the number of locations not allocated to the target field to just 9 locations or 0.05% (1 in 1775) and critically the numbers of time-consecutive locations outside the buffered target field was zero. For Sheep 2 with a GNSS cycle of 5 minutes, with 1543 locations over 11 days, 21.3% of raw data points were outside the fenceline. With a combination of rolling average and 10 m external buffer zone effectively placed every location within the field.

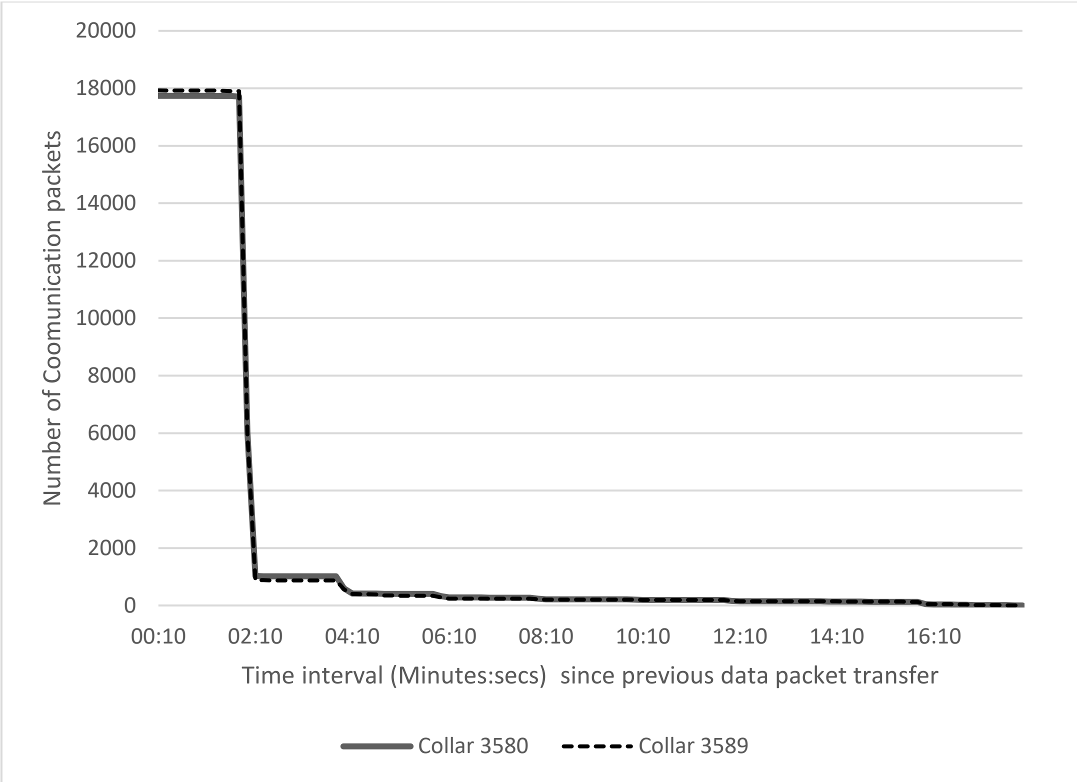

Figure 2: Performance of LoRA data packet transfers for two collars with a 2 minute duty cycle over 26 days

Table 1: GNSS – animal location – which field is the sheep in?

	Outside fenceline (of raw data points)	Outside when using a 10 point rolling average	Outside fenceline use 10m buffer	Outside fenceline methods combined
Sheep 1 (1 min. intervals)	29% (15,333)	20%	1.5%	0.05%
Sheep 2 (5 min. intervals)	21.3 (1,543)	1.9%	1.3%	0.001%

In Sheep Study C, all ewe collars displayed uneven distributions towards certain lambs during each deployment phase. Chi-square analyses estimated for each ewe collar identified highly significant results in favour of the related lambs ($p < 0.0005$). There were clear differences between the mean number of contacts made by each ewe and her related lambs (29.51±1.7), and the unrelated lambs (2.04±0.14) ($p < 0.0005$) as illustrated in Figure 3 for one ewe collar with all collared lambs. All ewe/lamb pairings had very similar patterns. In addition, there were also large differences in RSSI for the contacts that were registered. The means of related (-80.61±0.92) and unrelated (-91.12±0.31), as illustrated in distribution form in Figure 4, were again highly significantly different ($p < 0.0005$). So, not only did related lambs register dramatically more contacts, the nature of these contacts were stronger.

Overall, the highly significant results obtained, in terms of both contact number and distance associated with the contacts, suggests this is a very useful method to establish reliable ewe and lamb relationships. This could help to enable extensive hill flocks to benefit from genetic improvement, although sire identification would also need to be carried out. Nonetheless, the ability to relate the performance of the ewe to her lambs would provide valuable information in terms of traits such as lamb survival and growth.

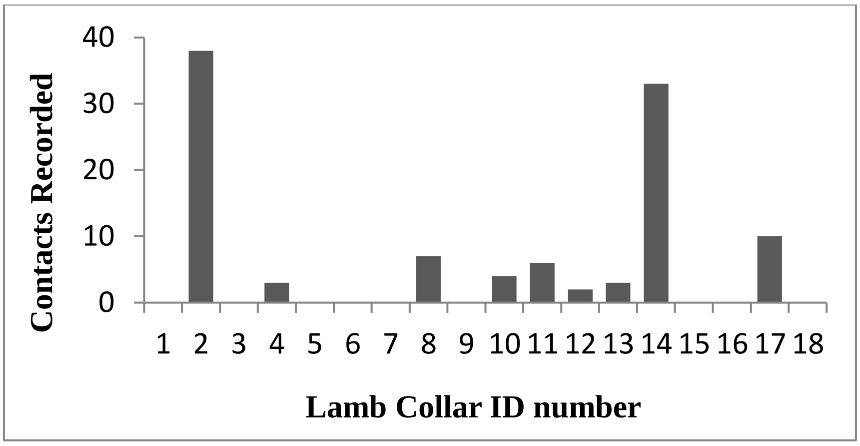

Figure 3: Ewe Collar contacts with different lambs (Lambs 2 and 14 are related twin lambs)

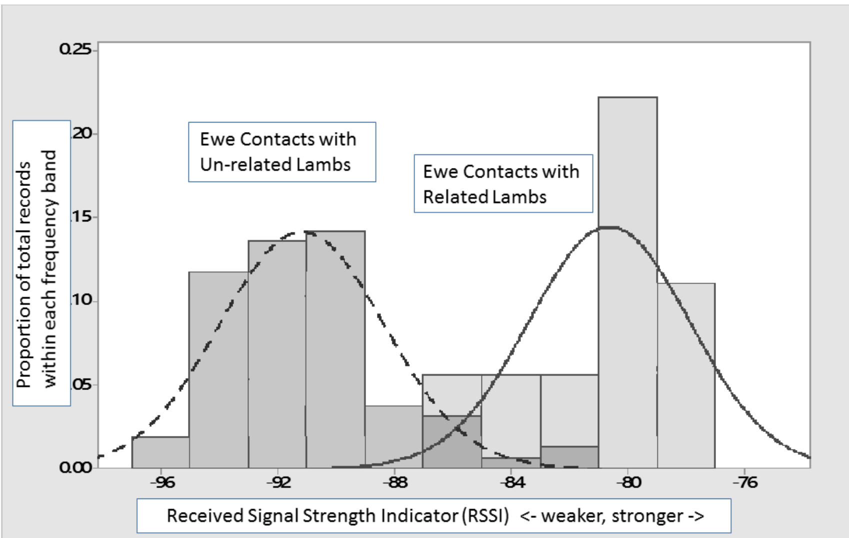

Figure 4: Data from ewe/lamb proximity pairings communicated showing Signal Strength (RSSI) distributions between proximity-logged related and un-related ewes/lambs

Cost Benefit Analysis

There are two main issues linked to the adoption of real-time monitoring technology; firstly will the technology provide useful information for decision support and secondly will there be satisfactory cost/benefit for the technology uptake.

There are then two further elements of improved production. The first is linked to direct gain in the number of live animals available for sale through improved survival of both adult breeding animals and young growing animals. The high losses of lambs in extensive systems are well documented (e.g. Waterhouse, 1996). There are many life/death scenarios in extensive systems, and there are many situations where interventions by stockpeople could make a difference. The challenge is to ensure that the location of any problem can be highlighted to the stockperson but that there is then sufficient time and resources to have a chance of success. With wearable technology combining real-time location and diagnosable behaviour, then both the location and putative diagnosis of the issue could be communicated to the stockperson.

A second element of productive gain in these systems is the potential to increase the size and value of the livestock sold. Increases in liveweight of weaned lambs or calves would typically provide an economic gain. The biological mechanism by which this could be achieved via PLF technology is challenging to ascribe. Using a well-documented PLF approach for sheep, using so-called Targeted Selective Treatment (TST) for stomach worm control, there were clear benefits in terms of more sustainable use of anthelmintic drugs, and some limited input savings, but the main conclusion of a series of studies is that body weight change was not affected (e.g. Morgan-Davies *et al*., 2018).

The proximity system for lamb maternal pedigree has a simpler set of cost benefits. Commercial services using tissue samples and DNA analysis cost upwards of £10 per lamb for lamb-ewe-ram diagnosis. Using proximity sensors, an accurate pedigree of lamb-ewe appears feasible within 1 week, allowing multiple uses of the same equipment. The commercial service being offered in Australia provides further evidence that commercial cost/benefit exists.

Steenvold *et al*. (2015), showed no benefits in productivity, savings or changes in technical management after implementation of sensor systems on a large number of dairy farms, so it is important that the PLF science community asks questions about cost/benefit alongside studies of technical proficiency. Furthermore, differences between intensive and extensive systems should also considered.

Conclusions

LoRa communication within the range of a LoRa gateway network was shown to be very effective, though may lead to data losses through loss of connection across the different stages of data transfer. There are also constraints of data through data packet length and data transmission interval (which affects power use). Advantages are that data are real-time, so data transmissions can be seen and therefore it is possible to problem-solve issues of both communication and data acquisition. Limits of data packet length forces decisions on which data can be collected and communicated, rather than ‘everything’. On-going developments with LoRa networks, and with gateway locations in remote environments, are needed. There are challenges for remote, extensively farmed areas with poor coverage of mobile phone networks and connections to the internet. Knowing where animals are in real time is valuable, especially in extensive environments. This complements other ‘behaviour’ information or alerts, because if an alert is received or a problem is identified then it is only through knowing where the animal is that action can be taken. For field-based systems, field location is important, but may be beyond the resolution of GNSS without use of runs of data. Proximity sensors show the capability to provide data on dam-offspring relationships essential for animal breeding and a practical alternative to

DNA testing which could be particularly valuable for sheep breeding in extensive systems. The need and financial value of real-time monitoring of this data is less clear. Combined technologies provide the best technical promise but all four technologies have particular challenges in terms of costs and benefits in extensive systems.

Cost-effective precision livestock farming technology and applications could be transformational in extensive systems, but better case studies are needed to highlight the production and welfare impacts and these should include cost/benefit analyses.

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