6. Description of the research project

The work covered by this experimental license amounts to a pilot study, as we attempt to develop a new way of assessing in-channel water temperatures in river systems. This pilot is a part of the USFW Lower Yuba River (LYR) Hallwood Floodplain Restoration project. The academic value of this study, as it pertains to salmonids is more thoroughly explained in the project description above. We seek to create accurate temperature maps of the LYR, which can later be applied to these salmonid models. To this end, we have used the Dash7 protocol at 433 Mhz to transmit temperature data over large expanses of river. This study will, in the first year cover about 4 km of river, and we hope to expand the network to the entire 30 km length of the LYR.

Dash7 operates using a foreground and background channel. Nodes within a mesh advertise on the background channel and communicate on the foreground channel. Dash7 has a consistent “tick” or clock across nodes of 1/1024 sec. This synchronization allows nodes to dynamically wake and sleep to listen for advertisements. When a node receives a background channel advertisement, that advertisement tells it when to expect a foreground data transmission. In this way, transmissions on any particular channel are kept to a bare minimum, and data transfer and processing is activated only when a data transmission is anticipated.

In an effort to fully comply with FCC Title 47 Part 15 (47 CFR 15), we have endeavored to modify the scheduling of advertisements and communications. We have also moved transmissions to multiple bands to ensure that transmissions are not burdensome on a particular frequency. What follows is an explanation not of the Dash7 protocol, but rather of our modifications thereof to substantially comply with 47 CFR 15. First, we have limited the per-node field strength.

Field Strength Calculations

47 CFR 15.231 has two limits: at 433 MHz (1) the field strength can only be ~ 11372 μV/m at 3 meter for periodic applications that are not at regular predetermined intervals otherwise and ~ 4549 μV/m at 3 meter for regular predetermined intervals. In our application, the transmitter and the relay nodes will be regular and predetermined intervals. Hence, we need to meet ~ 4549 μV/m at 3 meter.

The conversion of field strength to power density is given by the following equation

$$S = \frac{E^2}{3770}$$

where E is the field strength in volts/m, S is the power density in mW/cm^2. Based the above equation, the FCC requirement is $5.488966*10^{-6}$ mW/cm^2 at 3 meters. Since the deployment is occupational and in an environment where access is controlled, the time averaging must be done over a sliding window of 6 minutes. The allowed limits can follow the following relationship

$$\Sigma\, S_{exp} t_{exp} \;=\; S_{limit}\, t_{avg}$$

where S_{exp} power density level of the exposure, t_{avg} is the appropriate averaging time (6 mins), S_{limit} is the power density of the MPE limit (mW/cm^2), and t_{exp} is the allowable time of exposure for S_{exp}. For example if S_{limit} is 1 mW/cm^2 then $S_{limit}\, t_{avg}$ is 6 mV/cm^2. Hence, 2 mW/cm^2 is allowed if the time for exposure is at most 3 min in any 6 min interval.

The RF field strength S at a distance R is given by

$$S \;=\; \frac{EIRP}{4\pi R^2} = \frac{1.64\, ERP}{4\pi R^2}$$

where EIRP is the effective isotropically radiated power and ERP is the effective radiated power. For the RF field strength to be 5.488966*10^{-6} mW/cm^2 at 3 meters, the EIRP of the transmitter can be at most -22.36 dBm which corresponds to 0.00581 mW. Let α seconds denote length of time in a 6 mins (360 seconds) averaging interval for which the transmitter is active. Since the EIRP of the transmitter is 10 mW, using the required averaging technique shown above we get

$$\alpha\,(sec) \times 10\,(mW) \;=\; 360\,(sec) \times\; 0.00581\,(mW)$$

Form which we get $\alpha \;=\; 0.209\, sec$. Since the data rate is 55 Kbps, the number of bits that can allowed to be transmitted is $0.209 \times 55\, Kbps \;=\; 11505\, bits$. We now show that the size of a packet is significantly less than 11505 bits thereby meeting the FCC requirement.

Size of a Packet

The data packet will contain space for up to 10 sensors, the data from each sensor will be labeled using a 4 bits, and the data will be 10 bits. Apended to this data packet, will be our databasing information, including 8 bits for an ascii character which will label the data as “T” for temperature and 12 bits defining the node number. This yields a total data packet of 160 bits. The Dash7 protocol adds some additional addressing and overhead of 10 bits, and a CRC of up to 16 bits. We may implement some additional overhead for error correction. This yields a total transmitted packet of 186 bits, or under 24 bytes. The CC430 used for these transmissions, has the option of including forward error correction. This could add as much as 64 bytes to the payload. This would yield a total of about 88 bytes, or 704 bits. This is about 6% of the allotted maximum computed in the above section.

At 433 Mhz, and with scheduled, periodic transmissions, we will observe the stipulations of 47 CFR 15.231 paragraph e. This means limiting field strength at 3m of fundamental radiation to 1,500-5,000 μV/m, and spurious emissions to 150-500 μV/m. Further, transmissions must be less than 1 second, and followed by a break in transmission of at least 30 times the transmission length (but no less than 10 seconds).

We compute that given the whip antennas we intend to use, and a broadcast strength of 10 mW, we may transmit for up to 0.2 seconds in any 6 minute period for each node on each frequency. It is important to recall that we intend to utilize two channels, one foreground, and one background. This background channel is used to schedule data transfers on the foreground channel. The background channel will be consistent across nodes, however the foreground channels may vary by node, or by transmission to minimize interference on any given channel. While we intend to have numerous (20) intermediary nodes moving data to a single terminal node which will upload to a server over the internet, we anticipate having only six nodes generating data. In order to meet the restrictions laid out in 47 CFR 15.231, while still transmitting temperature data from all six sensor nodes, at least four times per hour, we propose the using the following schedule:

Transmitting node

1. The transmitting node advertises on the background channel for 200 ticks (1/1024 sec). This advertisements consists of a continuously repeated packet containing information about the data packet it will later send on the foreground channel. This packet will contain (a) the channel ID, and (b) ETA for the foreground transmission.
2. At the end of this advertising period, the transmitting node switches to the foreground channel (specified as (a) the channel ID in the advertisement on the background channel) and waits for the advertised ETA. At the advertised ETA, the transmitting node begins transmitting its data packet(s). Packets are anticipated to be ~16 Bytes, with a total data rate of ~ 6875 B/sec (55 kb/s), transmit of a single packet will take less than 0.0025 sec
3. After transmitting the data packet(s), the transmitting node switches to a reception state on the foreground channel anticipating a confirmation of receipt from the next node in the mesh.
4. If the transmitting node receives confirmation, it will sleep for 15 minutes, before taking another temperature reading and repeating the process. If the transmitting node does not receive a confirmation of receipt, it will wait a minimum of six minutes and will then attempt to repeat the transmission using the same protocol and scheduling above.

Receiving node

1. A receiving node polls the background channel for 2 ticks every 200 ticks. If the receiving node does not detect a signal above noise level, it returns to low power mode until the next polling time.
2. If the receiving node detects a signal above noise level on the background channel, it accepts a packet containing (a) channel ID and (b) ETA for a data packet. The receiving node waits in a low power state until the ETA.
3. At the ETA (b), the receiving node begins listening on the foreground channel specified by the channel ID (a) and accepts packets.

4. When the receiving node stops receiving packets, it switches to a transmission state on the foreground channel and sends a confirmation of receipt to the transmitting node.
5. This node then waits a minimum of 10240 ticks (10 sec) before initiating advertisement for the next upstream node, following the scheduling and protocol specified above in “transmitting node”. The next upstream node will then do the same, until eventually the terminal node is reached and the packet is uploaded over the internet to our server at UC Davis.

Communication facilities requested are necessary for research
We are installing distributed temperature sensors on 2.5 mi of river. These sensors need adequate range to span this distance without unwieldy numbers of intermediary transmitters. These transmitters need to be remotely located, without direct access to power, as such they must use little enough power to be battery powered. The best candidate for such a system is the Dash7 protocol operating at 433 Mhz. This protocol is specifically designed for low-power over vast distances, with small data packet sizes.

Existing communication facilities are inadequate
There is really no other existing communication protocol which can cover the distances required using so little power. The best candidate would be ~900 Mhz, which is used by XeeBee and Zigbee. The Dash7 protocol can even be used at 900 Mhz. Unfortunately, using a 900 Mhz spectrum would have halved or quartered our transmit distance, and would have increased our power use. This network will use the unlicensed 433 Mhz frequency, but will be extremely low-power, and the software is specifically designed to follow the rules for scheduled transmissions at 433 Mhz.