Lotek Tag Lifespan Model

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We need some reasonable upper bound for the lifetimes of tags, by battery and BI.

Lotek provides a short table here:

http://www.lotek.com/bird+bat-nano.pdf (As of 1 April, 2016)

and there are additional models listed in "ANTC Spec Sheet.pdf" (no source), including the only numbers for battery type "3-1". Since lifetime is listed as depending only on the battery (numeric portion of model string), we model on that.

```
lt = as.tbl(read.csv("./lotekTagLifespanByBatteryAndBI.csv"))
```

Add inverses of columns bi and dutyCycle, for modelling

```
ls = lt %>% mutate(biInv = 1.0 / bi, dcInv = 1.0 / dutyCycle)

print(ls)
```

```
# A tibble: 72 x 6
   battery    bi dutyCycle lifespan biInv dcInv
    <fctr> <dbl>     <dbl>    <dbl> <dbl> <dbl>
 1       1    10       0.5       45   0.1     2
 2       1    10       1.0       33   0.1     1
 3       1     2       1.0       10   0.5     1
 4       1     5       1.0       21   0.2     1
 5       2    10       0.5       71   0.1     2
 6       2    10       1.0       52   0.1     1
 7       2     2       1.0       16   0.5     1
 8       2     5       1.0       33   0.2     1
 9     3-1    10       0.5       87   0.1     2
10     3-1    10       1.0       64   0.1     1
# ... with 62 more rows
```

A simple model assumes that the battery capacity, K, depends on the battery model, and that tag power consumption r is a sum of a baseline rate r_0 plus a pulse-dependent rate r_1. All tags transmit 4 pulses per burst, so the pulse-dependent rate r_1 depends only on duty cycle and burst interval like so: $r_1 = r_p * \frac{dutyCyle}{BI}$

The full non-linear model is :

$$lifespan = \frac{K}{r_0 + \frac{r_p * dutyCycle}{BI}}$$

This is over-parameterized (we can divide top and bottom by r_0 to get a model with two parameters), so we simplify by rewriting K/r_0 as D, the number of days of battery life at the baseline rate, and r_p/r_0 be r_t, the relative rate of power consumption during transmission, versus baseline. The new model is:

$$lifespan = \frac{D}{1 + \frac{r_t * dutyCycle}{BI}}$$

We fit the model to each type of battery:

```
par = res = pred = NULL
bnames = unique(ls$battery)
for (m in bnames) {
    res[[m]] = nls(lifespan~D / (1 + rt * dutyCycle / bi),
                   subset(ls, battery==m), list(D = 500, rt = 5))
    par = rbind(par, c(coefficients(res[[m]]), max(residuals(res[[m]]))))
    pred = rbind(pred,
                 data.frame(
                     battery=m,
                     bi=1:40,
                     lifespan=predict(res[[m]], list(bi=1:40, dutyCycle=1))
                 ))
}
rownames(par) = bnames
colnames(par) = c("D", "rt", "Max Residual (days)")
```

Stu Mackenzie pointed out there is a light-weight version of the *NTQB-1* which he's dubbed *NTQB-1-LW*, with "~2/3 the lifetime of the NTQB-1". For now we'll assume that means the D parameter for that model is 2/3 that for the NTQB-1

```
par = rbind(c(par[["1","D"]] * 2 / 3, par[["1", "rt"]], NA), par)
rownames(par)[1] = "1-LW"
pred = rbind(data.frame(
    battery="1-LW",
    bi=1:40,
    lifespan=par[["1-LW", "D"]] / (1 + par[["1-LW", "rt"]] / (1:40)))
  , pred)

## mark which rows are measurements
pred = cbind(pred, isMeasured = paste(pred$battery, pred$bi) %in% paste(lt$battery, lt$bi))
```

Now map model names to batteries. We do this as a simple table because the naming scheme isn't consistent enough to bother doing it programmatically.

```
## Models and the batteries they correspond to.  Note that
## we include a model called 'unknown' which corresponds to
## a battery called 'unknown' that is assigned a life equal
## to the average of those for NTQB-2, NTQB-3-2.
## This forces a warning to be emailed to the motus admin whenever
## the metadata cache is updated, because an unmodelled tag
## is a serious metadata issue.

modelBattery = list(
"NTQB-1-LW"  = "1-LW",
"NTQB-1"     = "1",
"NTQB-2"     = "2",
"NTQB-3-2"   = "3-2",
"NTQB-4-2"   = "4-2",
"NTQB-6-1"   = "6-1",
"NTQB-6-2"   = "6-2",
"NTQBW-3-2"  = "3-2",
```

```
"NTQBW-2"    = "2",
"NTQBW-4-2"  = "4-2",
"NTQBW-6-2"  = "6-2",
"ANTC-M1-1"  = "1",
"ANTC-M2-1"  = "2",
"ANTC-M3-1"  = "3-1",
"ANTC-M3-2"  = "3-2",
"ANTC-M4-2"  = "4-2",
"ANTC-M4-2S" = "4-2",
"ANTC-M4-2L" = "4-2",
"ANTC-M6-1"  = "6-1",
"ANTC-M6-2"  = "6-2",
"ANTCW-M1-1"  = "1",
"ANTCW-M2-1"  = "2",
"ANTCW-M3-1"  = "3-1",
"ANTCW-M3-2"  = "3-2",
"ANTCW-M4-2"  = "4-2",
"ANTCW-M4-2S" = "4-2",
"ANTCW-M4-2L" = "4-2",
"ANTCW-M6-1"  = "6-1",
"ANTCW-M6-2"  = "6-2",
"ACT-521" = "521",
"ACT-626" = "626",
"ACT-393" = "393",
"NTQB2-1" = "2-1",
"NTQB2-2" = "2-2",
"NTQB2-3-2" = "2-3-2",
"NTQB2-4-2" = "2-4-2",
"NTQB2-4-2S" = "2-4-2",
"NTQB2-5-1" = "2-5-1",
"NTQB2-6-1" = "2-6-1",
"NTQB2-6-2" = "2-6-2"
)

modPar = NULL
for (b in names(modelBattery))
    modPar = rbind(modPar, par[modelBattery[[b]],])
rownames(modPar) = names(modelBattery)
```

The results show good agreement with the data table from Lotek:

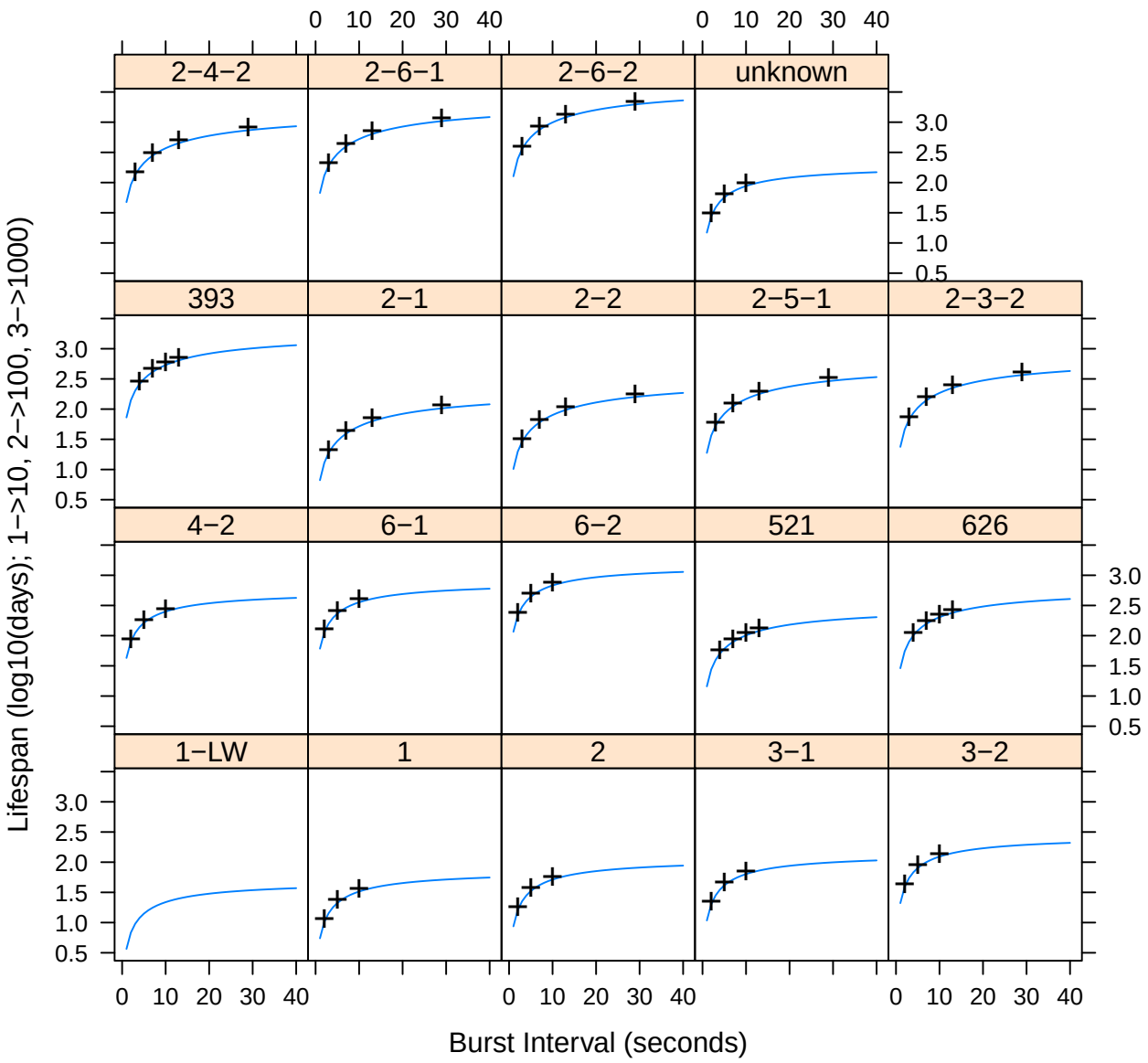
```
print(round(par, 1))
```

```
             D   rt Max Residual (days)
1-LW      48.5 12.3                  NA
1         72.8 12.3                 0.3
2        114.7 12.2                 0.4
3-1      138.5 11.8                 0.4
3-2      271.6 11.9                 0.2
4-2      547.0 11.8                 0.2
6-1      775.5 11.7                 0.1
6-2     1469.0 11.7                 0.2
521      304.1 20.1                 1.3
```

```
626      608.3 20.1                2.6
393     1839.8 24.3                3.3
2-1      213.5 31.1                0.2
2-2      332.3 31.6                0.2
2-5-1    601.7 31.0                0.1
2-3-2    759.8 31.0                0.2
2-4-2   1522.7 31.1                0.1
2-6-1   2160.0 31.1                0.4
2-6-2   4083.4 31.1                0.3
unknown  193.1 12.0                0.3
```

The parameter r_t can be interpreted as the ratio of energy consumed during 1 second with a burst to that consumed during 1 second without a burst. Estimates of this parameter vary only by 5% across tag types, and in monotonic fashion, perhaps due to variation in battery internal resistance. The table provided by Lotek only covers $2 <= BI <= 20$ (the larger value from BI=10s @ 50% duty cycle); curves are extrapolated down to 1s and from 20 to 40s using the fitted model.

```
xyplot(log10(lifespan)~bi|as.factor(battery), pred,
       main="Reported (+) and Predicted Tag Lifespan\nby Battery Type and Burst Interval",
       xlab="Burst Interval (seconds)",
       ylab="Lifespan (log10(days); 1->10, 2->100, 3->1000)",
       type="l",
       panel = function(x, y, type, subscripts, ...) {
           panel.xyplot(x, y, type, ...)
           panel.points(x[pred$isMeasured[subscripts]], y[pred$isMeasured[subscripts]], pch="+", cex=2,
           }
       )
```


Reported (+) and Predicted Tag Lifespan
by Battery Type and Burst Interval
2−4−2
2−6−1
2−6−2
unknown
393
2−1
2−2
2−5−1
2−3−2
4−2
6−1
6−2
521
626
1−LW
1
2
3−1
3−2
Lifespan (log10(days); 1−>10, 2−>100, 3−>1000)
Burst Interval (seconds)
0
10
20
30
40
0.5
1.0
1.5
2.0
2.5
3.0