Stochastic modified KiBaM

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What is Stochastic Modified KiBaM ?

- The Stochastic KiBaM models battery discharge as 3-dimensional Markov process which is a stochastic extension of the Kinetic Battery model with certain refinements and additional parameters for accuracy[1].

Few words about KiBaM.

- Consists of two wells, Available well and Bound well.
- The available-charge well supplies electrons directly to the load, the bound-charge well supplies electrons only to the available-charge well.
- The rate of charge flow between the two wells is set by k and the difference in the heights of the two wells, h1 and h2.
- when h1 is zero the battery is fully discharged.
- Parameter c is a capacity ratio and corresponds to the fraction of total charge in the battery that is readily available.[1]

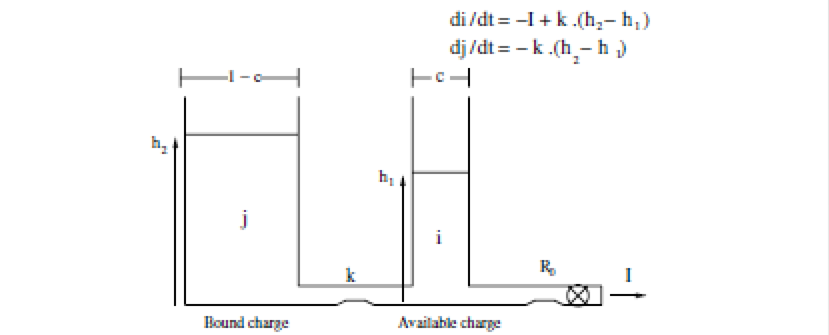


Figure 2. Kinetic Battery Model, models battery as two wells of charge - available and bound

$$di/dt = -I + k.(h_2 - h_1)$$
$$dj/dt = -k.(h_2 - h_1)$$

The Modified KiBaM.

- Parameter i represents the amount of charge in the available charge well and j represents charge in bounded charge well at any point during the battery life time.
- The rate of charge flow between the two wells is a function of k’, height h2 and the difference in the heights of the two wells, h1 and h2

$$h_2.(1-c) = j$$
$$h_1.c = i$$

$$J = k'.h_2.(h_2 - h_1)$$

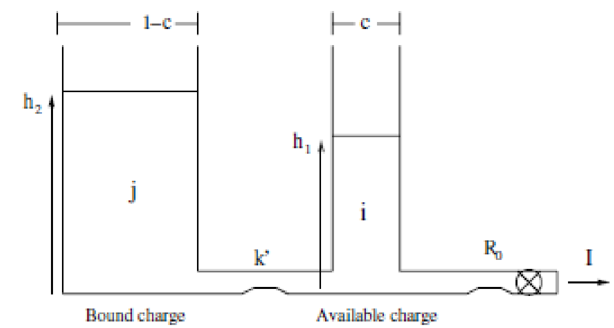


Figure 4. Modified KiBaM with rate of transfer between two wells is equal to $k'.h_2.(h_2 - h_1)$

- The dependence on height h2 reflects the observation that a battery has more tendency to recover when it has more charge left.

Stochastic KiBaM as three dimensional Markov chain

- The battery is modeled using three state parameters (i, j, t), making a three dimensional Markov chain structure.
- t is the length of the current idle slot, t is measured in time units, where a time unit is the least count of the time in simulation[1].

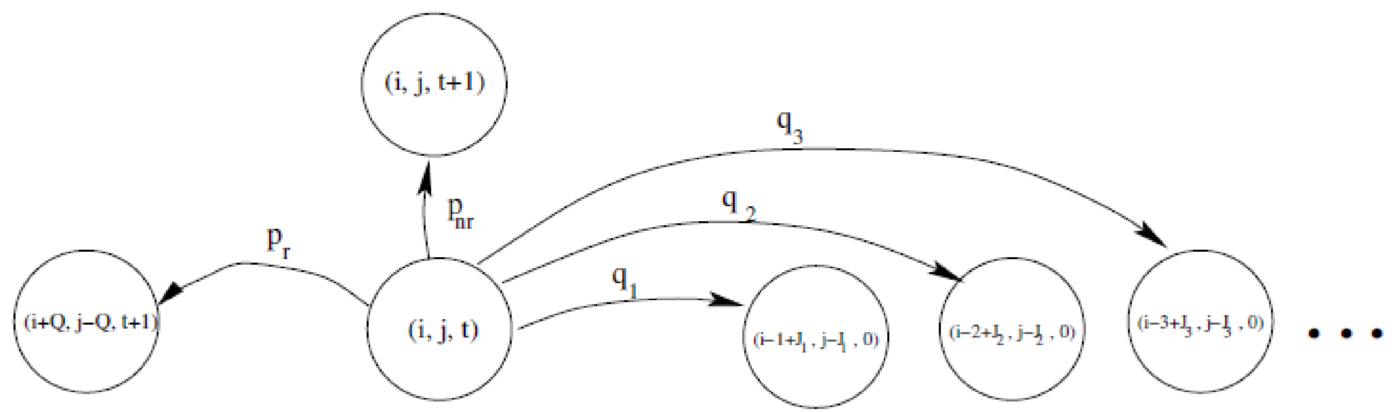


Figure 5. Transition probabilities

The state Transition

- The following equations summarizes the transitions and their probabilities respectively.

$$(i,j,t) \longrightarrow \begin{cases} (i+Q, j-Q, t+1) & (i) \\ (i,j,t+1) & (ii) \\ (i-I+J, j-J, 0) & (iii) \end{cases}$$

- The probability for transition (i) and (ii) respectively are
- The probability for transition (iii) is qI

$$p_r(i,j,t) = q_0.p(t)$$
$$p_{nr}(i,j,t) = q_0.(1-p(t))$$

- qI is the probability that in one time unit, called a time slot, **I** charge units are demanded.
- I charge units per unit time are drawn from the available charge well while some charge **J,** being replenished by the bounded charge well, to available charge well.

$$(i,j,0) \longrightarrow (i-I+J, j-J, 0)$$
$$J = k'.h_2.(h_2-h_1)$$

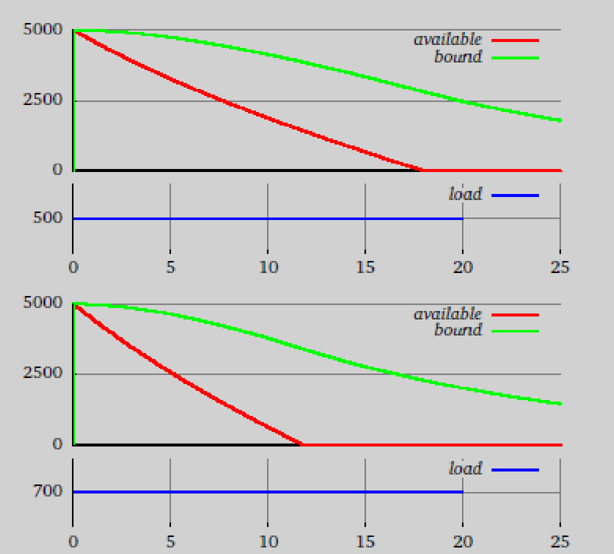
The state Transition

- If there are idle periods in between discharges, the battery can partially recover its charge during these idle times.
- The probability of an idle slot occurs be q0.
- During a given idle slot the battery may or may not recover.pr(i, j, t) and pnr(i, j, t) represent probability of recover and not recover.
- The quanta(**Q**) of charge it recovers depends on the current state of the battery i.e. height h2 , (h2 − h1) and the granularity of time.
- The quanta(**Q**) of recovery is calculated so as the charge recovered for an infinitely long idle slot is equal to total charge that needs to be transferred between the two wells before there heights are equalized.
- If there is no recovery then there will be no change in the values of parameter i and j while t is incremented by one for the next successive idle slot.

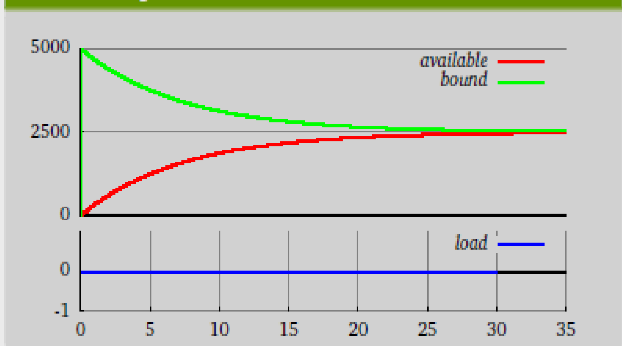
How useful is KiBaM ?

- It gives an intuitive idea of how and why the recovery occurs and explains about rate capacity effect.
- The rate capacity effect is automatically incorporated in the model, because as the discharge current increases, charge in the available well decreases more rapidly giving the bound charge well less time to replenish the available charge well and battery is declared to be discharged even though there is a lot of charge left inside the bound charge.
- The model allows to recover when there is Idle slot. –Recovery effect

Rate-capacity effect



Recovery effect



Implementing the model

- The simulation model consists of:
  1. Energy Consumer.
  2. Battery Model.

- The parameters for the Battery model.
  1. The charge in available well (i)
  2. The charge in bound well (j)
  3. The time unit (t). Least count of time in simulation (100ms)
  4. The rate constant k or k’
  5. The fraction of charge in available well(c)
  6. The probability for transition qI.
  7. The probability of recovery Pr.

Implementing the model

- The energy consumer can poses either idle state (deep sleep) or active state (send mode and receive mode)
- The energy consumer acknowledges battery model when ever there a state change through a message.
- The message consists of current state, requested charge
- In response to the message, the battery model gives the requested current.
- The model updates the value of i,j and t.
- The simulation stops when there is no charge in available well(i=0)
- The battery model notifies this energy consumer through a message

Implementing the model

- During active period, qI charge units are drawn from the battery

$$(i, j, 0) \longrightarrow (i - I + J, j - J, 0)$$
$$J = k'.h_2.(h_2 - h_1)$$

- At each step of the simulation, model calculate the average current over each time slot, converting it into appropriate number of charge units depending on the time unit of the simulation.
- During idle period recovery occurs depending on the recovery probability(pr).
- The quanta(**Q**) of recovery is calculated as follows:[5]

$$\begin{cases} \frac{d\gamma}{dt} & = -i(t), \\ \frac{d\delta}{dt} & = \frac{i(t)}{c} - k'\delta, \end{cases}$$

I. When there is no current $\frac{d\delta}{dt} = -k'\delta.$

Implementing the model

- The solution to this differential equation is given by[5]:

$$\delta(t) = \delta(t_0)e^{-k't}.$$

  - Where t is time step in simulation.
- From the d(t) new height (h1’) can be found as:

  h1’=qtotal-d(1-c)

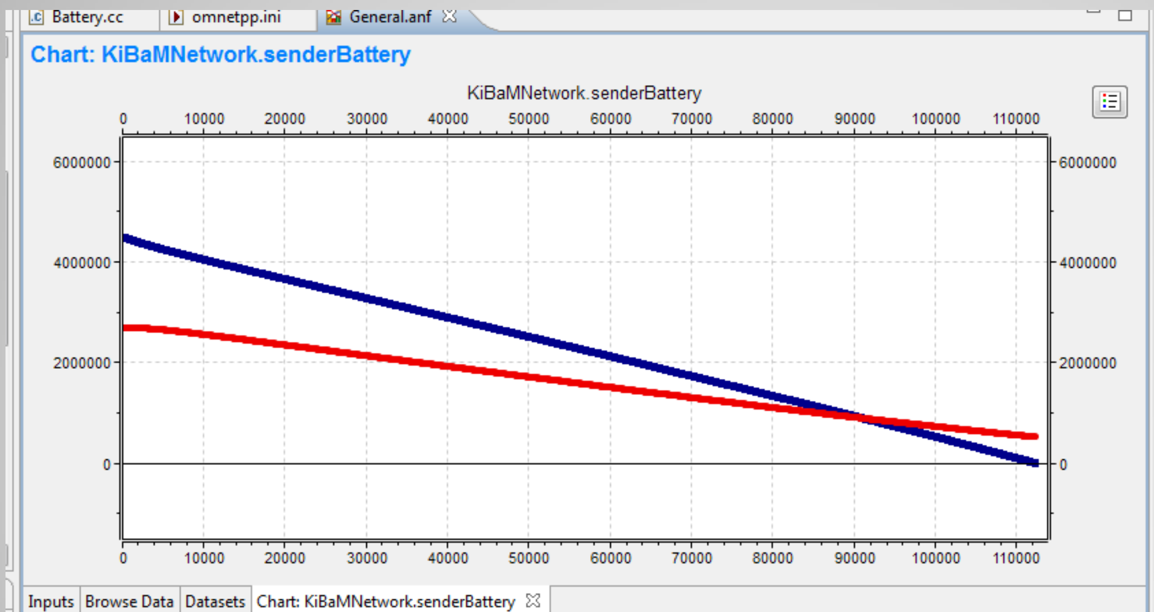
  Where qtotal is i+j
- The quanta(**Q**) is

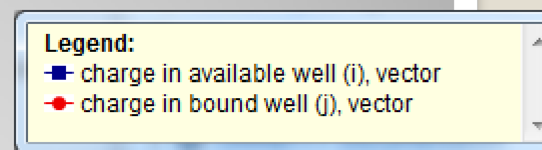
  Q=(h1’-h1)c
- K’ is taken as K/h2(max).

Analysis of simulation.

- Battery Life vs Sending Interval
  - Sending interval=20s
  - Message length=1024 bytes
  - K=4.5*10^(-5)
  - Battery Life:112284 s

	CC2530[b] 802.15.4 (Microcontroller & Transceiver)
Min Voltage	2.0 V
Deep Sleep	200 µA
RX	24.3 mA
TX (min)	28.7 mA
TX (max)	33.5 mA

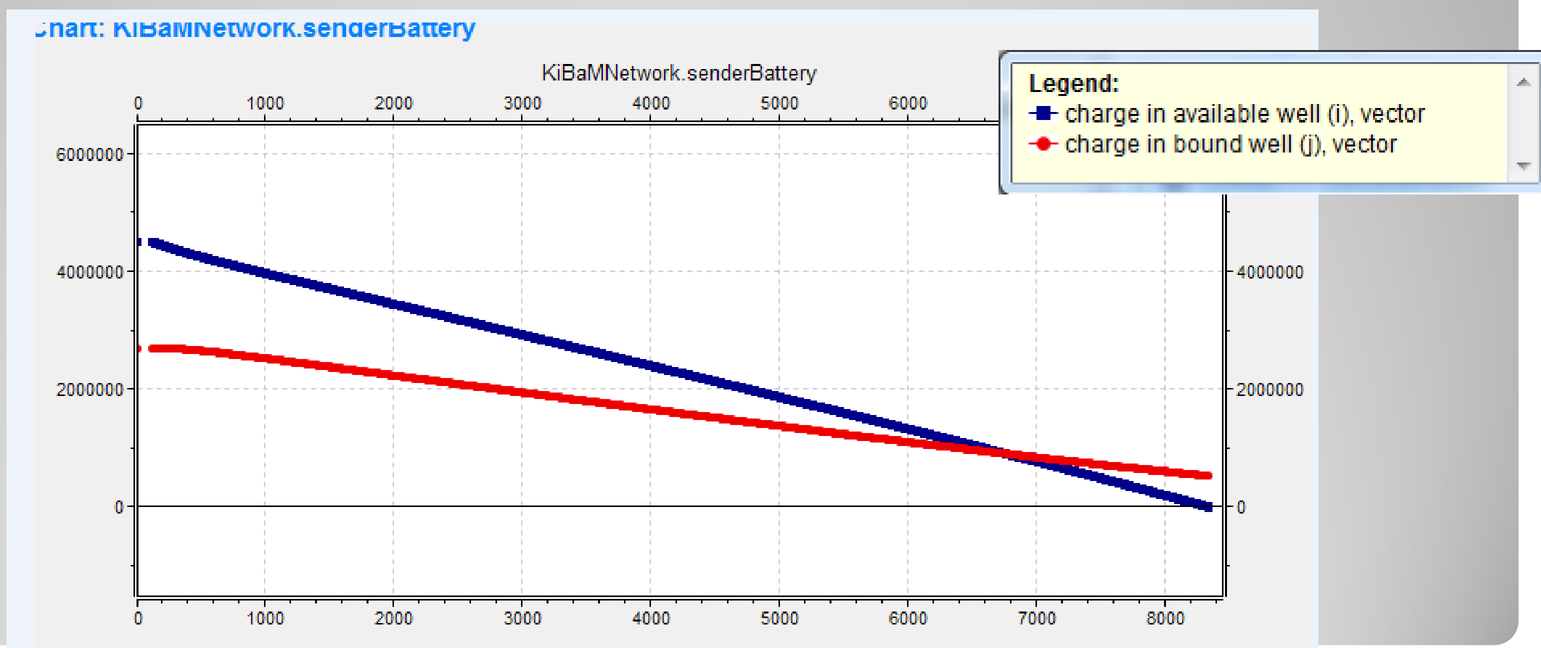




Analysis of simulation.

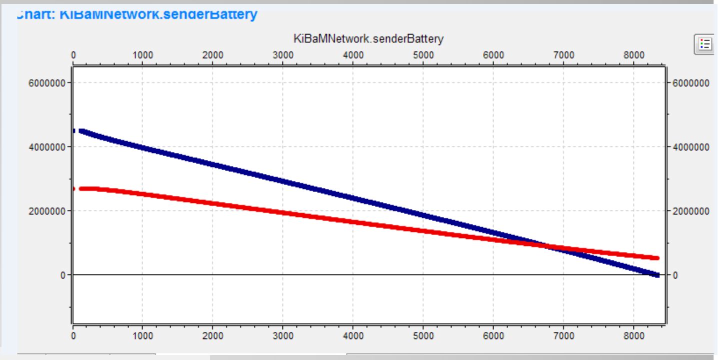
- Battery Life vs Sending Interval
  - Sending interval=1s
  - Message length=1024 bytes
  - K=4.5*10^(-5)
  - Battery Life:8328.4 s

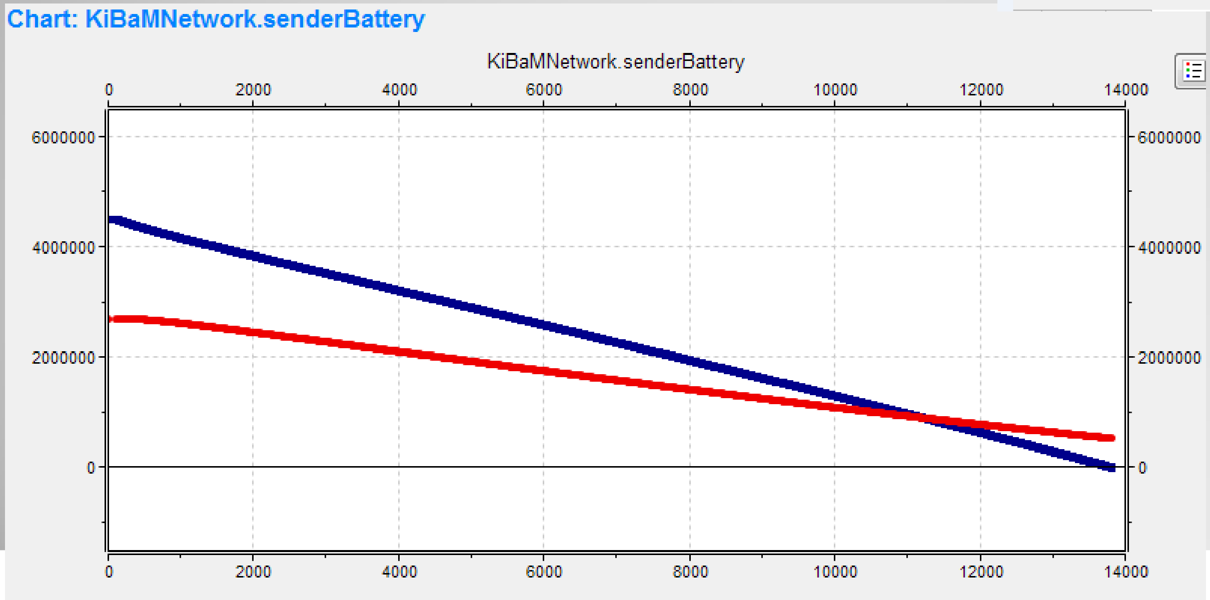
	CC2530[b] 802.15.4 (Microcontroller & Transceiver)
Min Voltage	2.0 V
Deep Sleep	200 µA
RX	24.3 mA
TX (min)	28.7 mA
TX (max)	33.5 mA



Analysis of simulation.

- Battery life vs Message Length
  - Sending interval=1s
  - Message length=512 bytes
  - K=4.5*10^(-5)
  - Simulation Time taken:13800.5s

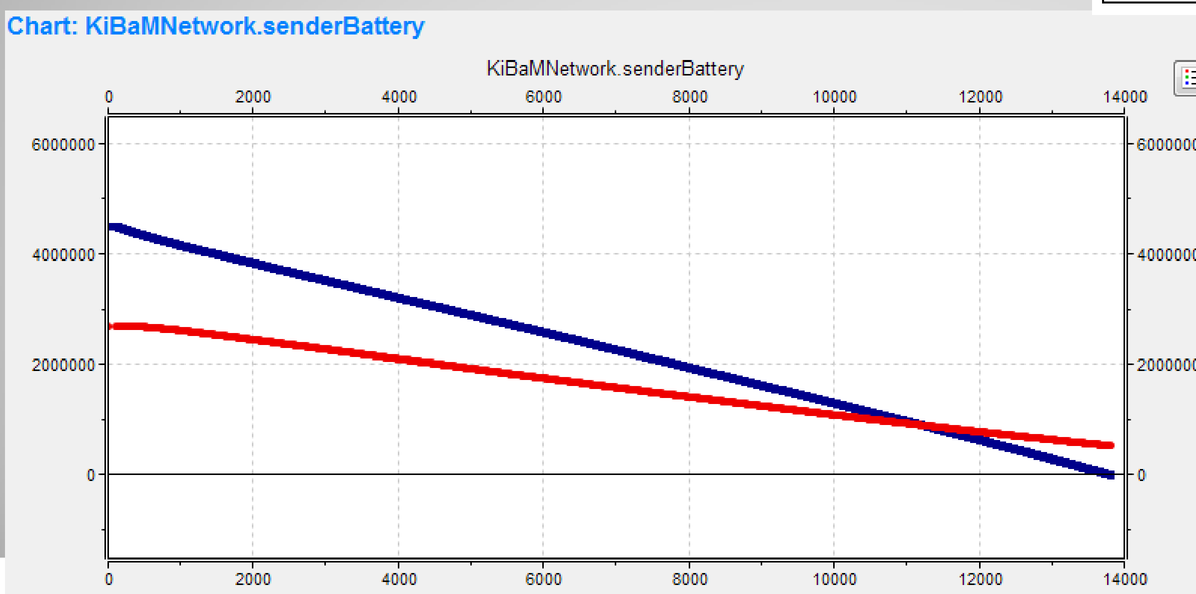




Analysis of simulation.

- Battery life vs Discharge Profile
  - Sending interval=1s
  - Message length=512 bytes
  - K=4.5*10^(-5)
  - Simulation Time taken:13800.5s

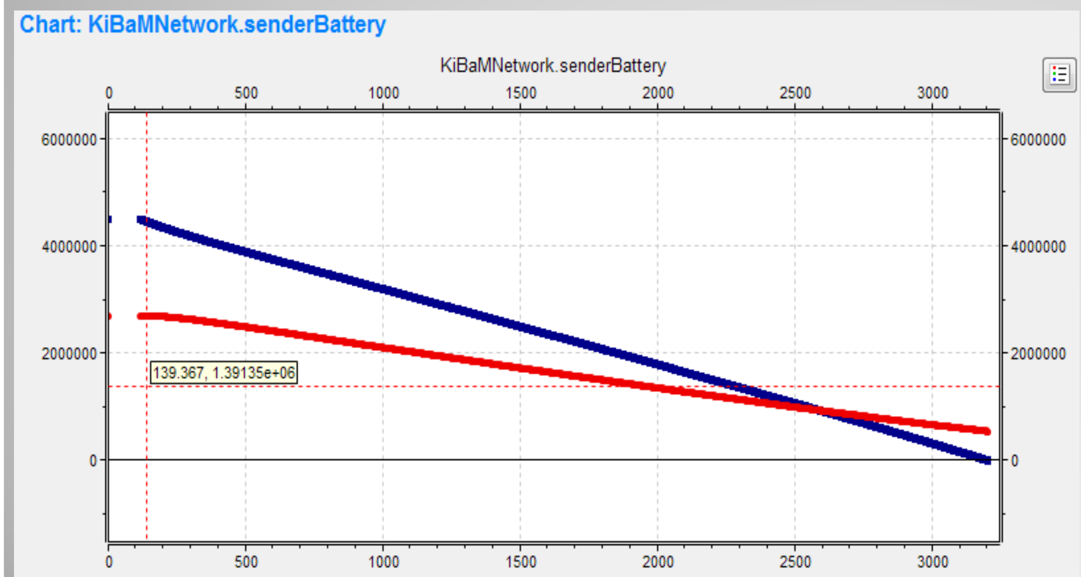
	CC2530[b] 802.15.4 (Microcontroller & Transceiver)
Min Voltage	2.0 V
Deep Sleep	200 μA
RX	24.3 mA
TX (min)	28.7 mA
TX (max)	33.5 mA

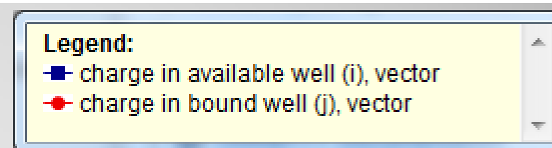


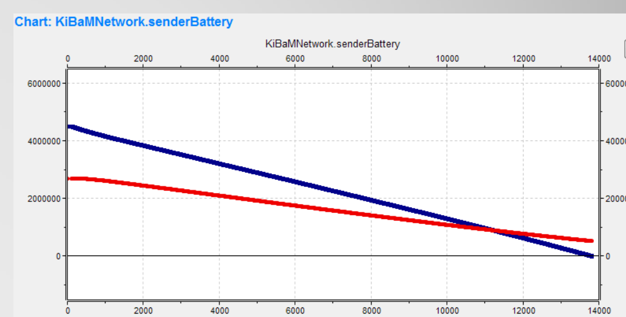
Analysis of simulation.

- Battery life vs Discharge Profile
  - Sending interval=1s
  - Message length=512 bytes
  - K=4.5*10^(-5)
  - Simulation Time taken:3201.4 s

	ESP8266[c] WiFi (Microcontroller & Transceiver)
Min Voltage	1.7 V
Deep Sleep	10 µA
RX	60 mA
TX (min)	135 mA
TX (max)	215 mA







Conclusion.

- Although many internal factors influence the performance of cell , sending interval, message length and energy expenditure during activity are plays major role in Battery Life.
- As sending interval increases, Idle period decreases and this block battery to replenish(recovery effect)
- As message length increases, transmission time increases battery life decreases
- As energy expenditure increases, battery drains fast (capacity effect)

References

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THANK YOU