Adaptive Contact Probing Mechanisms for Delay Tolerant Applications

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Outline

- Introduction
- Modeling contact processes
- Real world contact traces
- Designing energy efficient probing algorithm
- Conclusion
Delay tolerant network

- **Features:**
  - A end-to-end path may not always exists at any time
  - The round-trip time may be extremely long
  - Mobile nodes exchange data when they meet each other

- **Examples**
  - Dating applications
  - Advertisement
Energy consumption of DTN

- Communication in DTN is based on neighbor discovery
- Mobiles are normally battery powered
- Continuously search for data exchange opportunities can quickly exhaust the battery
- Example
  -- Bluetooth discovery process consumes as much energy as phone calls on mobile phones
  -- With discovery interval of 30 seconds, mobile phone need to recharge more than one times per day
Energy efficient neighbor discovery

- **Goal**

  Reduce the energy used in neighbor discovery, while not missing too many contacts

- **Assumptions**
  -- *Each probe cost the same amount of energy*
    
    Reduce energy → Reduce the number of probes
  
  -- *Probes are impulses in time*
  
  -- *Probes can find all contacts within communication range*

- **Method**

  -- *Modeling and analysis of contact process*
  
  -- *Study the real world contact pattern*
Contact model

- The contact model from the perspective of one device
- Abstracted as a process with *i.i.d. contact duration* distribution and *inter-contact time* distribution
- Enables methods to analysis the process
Missing probability

- If the device do not probe during the contact duration, the contact will be *missed*.

- If the device has no information about the contact process, using constant probing interval is the optimal solution.

- If the contact arrival rate is not changing with time, then the missing probability is only related to the contact duration distribution and probing interval, *irrespective* to the contact arrival rate.

\[ P_{\text{miss}}(T) = \frac{1}{T} \int_{0}^{T} F_D(x) \, dx \]
Missing probability vs. Energy

- Exponential
- Uniform
- Pareto (k=2)
Missing probability

- The device cannot precisely measure the missing probability
- We can infer the missing probability through the *short contacts* detected by the device
- For given contact duration distributions, such as uniform, exponential and Pareto distribution, we directly calculate missing probability and short contact probability when given the probing interval
Adaptive scheme I

- Adapt to the contact distribution
- Observe the short contact probability and adapt the probing interval
- Works for slowly varying processes
- Can guarantee a hard contact missing probability over all time durations
Time-varying contact arrival rate

- When the contact arrival rate is **time-varying** and we can predict the arrival rate, we can also adapt to the contact arrival rate

- Use high probing frequency when the contact arrival rate is high, so that can be catch most contacts

- Overall, the missing probability will be minimized
Optimal probing interval

- Formulated as convex optimization problem

\[
\begin{align*}
\text{Maximize} & \quad \sum_i (1 - P_{\text{miss}}(T_i)) \\
\text{s.t} & \quad \frac{L}{T_i} < N \\
& \quad T_i > 0
\end{align*}
\]

- Assume that the contact duration distribution is stationary. The optimal probing interval can be derived when the arrival rates are known

\[
T_i^* = \frac{C}{P_{\text{miss}}(T_i^*)}
\]
Adaptive scheme II

- Predict the contact arrival rate
- Solve the equation

\[ T_i^* P_{miss}^{'}(T_i^*) = \frac{C_i}{T_i^*} \]

- to find the optimal probing interval for a given duration
- Optimize the long-term missing probability and energy tradeoff
- Short term missing probability is high
Real world contact logging

- Use Bluetooth Mobiles carried by 9 volunteers
- Discovery interval is 30 seconds, 24/7
- Collected data for 3 months, totally 12,332 unique devices are discovered
- Data can be used for both analysis and simulation
Contact duration distribution

- Contact duration distribution is Pareto with $k=0.85$
Correlations

Correlation in short term is high → predictable arrival rate
Self similar contact patterns

- The R/S test shows the process is self similar
- Hurst parameter = 0.76
A 24 hours correlation period can be seen
Varying contact arrival rate

- Obvious arrival rate change according to time of day
What we learned from the data

- The arrival rate changes at different time
- The process is self similar and has high correlation in short time periods. This shows we can predict the arrival rate to some extent.
- Adaptive scheme I may not be useful due to Pareto distributed contact duration
- Adaptive scheme II is promising
Simulations on real contact logs

- Constant probing rate, verify the theory
Adaptive schemes

- Constant probing interval
- Use time of day information
- AIMD
- STAR (Short Term Arrival Rate estimation)
- Ideal scheme (perfectly predicts the arrival rate of next hour)
Performance

![Graph showing performance improvement over time with different algorithms. The x-axis represents the probing interval (seconds), and the y-axis represents the probability of miss ($P_{\text{miss}}$). The graph compares Non-adaptive, Ideal, and various adaptive algorithms including Fixed probing interval, Ideal algorithm, TOD, AIMD, and STAR. The x-axis ranges from 0 to 700 seconds, and the y-axis ranges from 0.0 to 0.5.]
Conclusion

- The contact arrival pattern can be modeled as a random process
- Bluetooth based experiments shows the human behavior patterns
- Based on different applications, we can use different adaptive schemes
- Synthetic Contact Models can also be derived from the real data patterns
Thank you!
STAR

- Measure the short term average arrival rate
- Gradually increase the contact probing interval, and sharply reduce it when finds a new contact
- Use day of time information to improve the performance
- Not sensitive to the k value
- Performs 20% better than AIMD
STAR trace log

![Graph showing probing intervals and time in hours for Ideal algorithm, AIMD, and STAR.](image)
STAR with different $k$