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

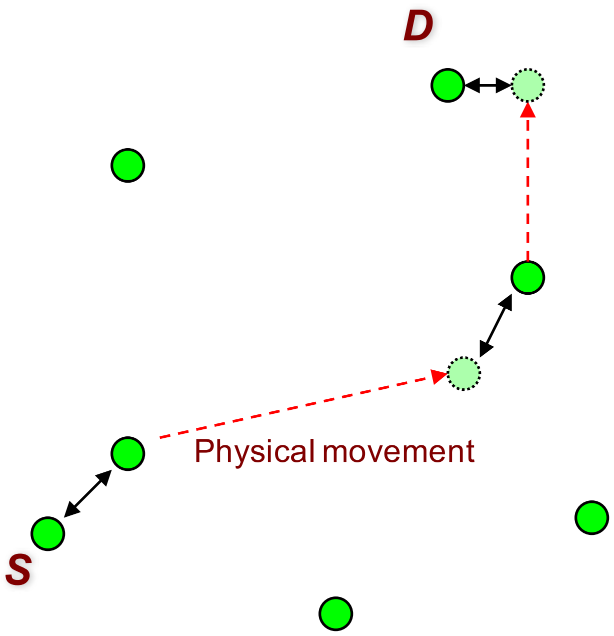
  -- The round-trip time may be extremely long

  -- 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*

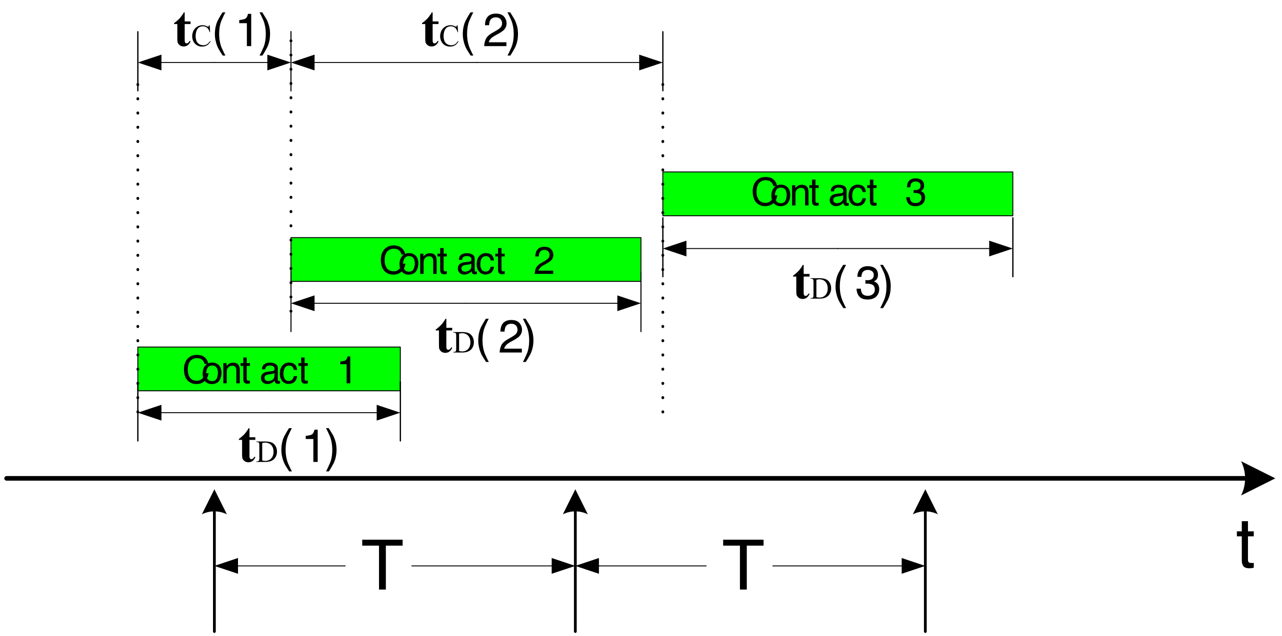
-- *Probes can find all contacts within communication range*

- **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

$$P_{miss}(T) = \frac{1}{T}\int_0^T F_D(x)dx$$

Missing probability vs. Energy

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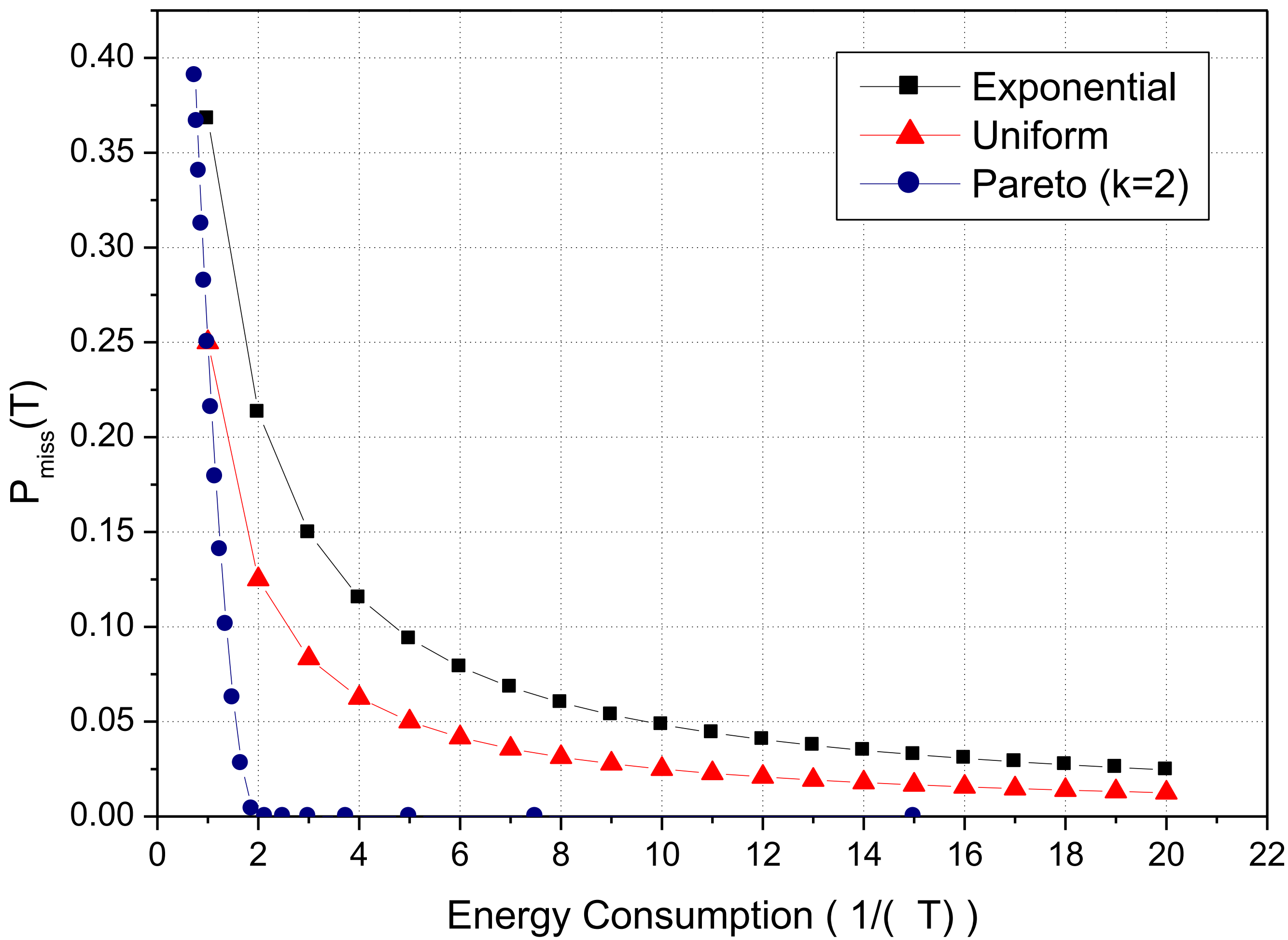


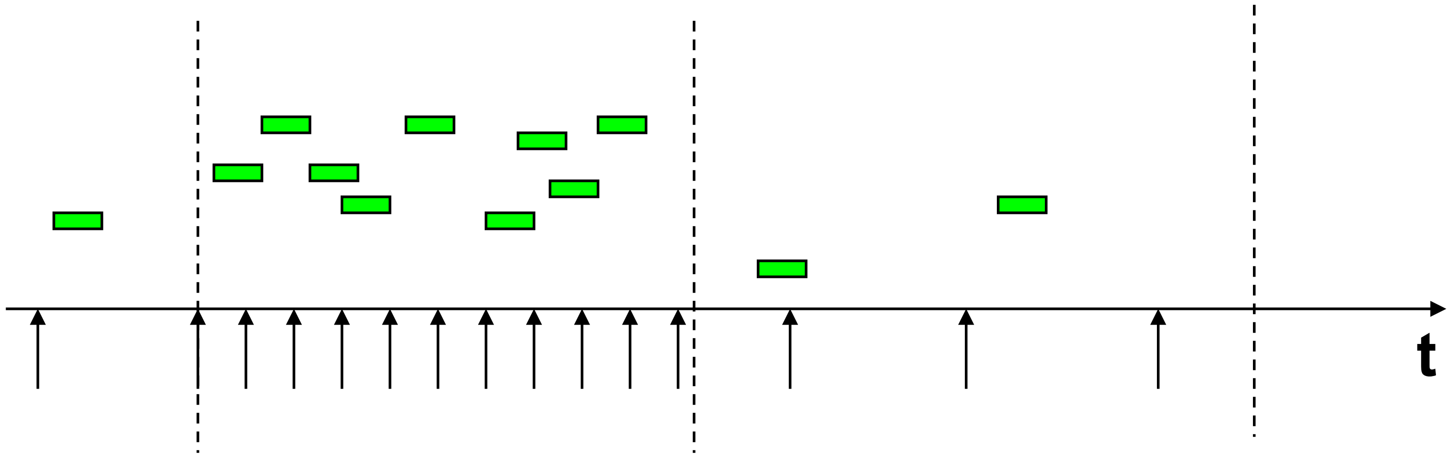
Missing probability

- 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

$$\text{Maximize} \quad \ _{i}\ {}_{i}(1 \quad P_{miss}(T_i))$$

$$s.t \quad \ _{i} \frac{L}{T_i} < N$$

$$T_i \quad 0$$

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

$$T_i^{*2} P_{miss}^{'}(T_i^{*}) = \frac{c}{\ _i}$$

Adaptive scheme II

- Predict the contact arrival rate
- Solve the equation

$$T_i^{*2} P'_{miss}(T_i^*) = \frac{c}{\quad i}$$

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

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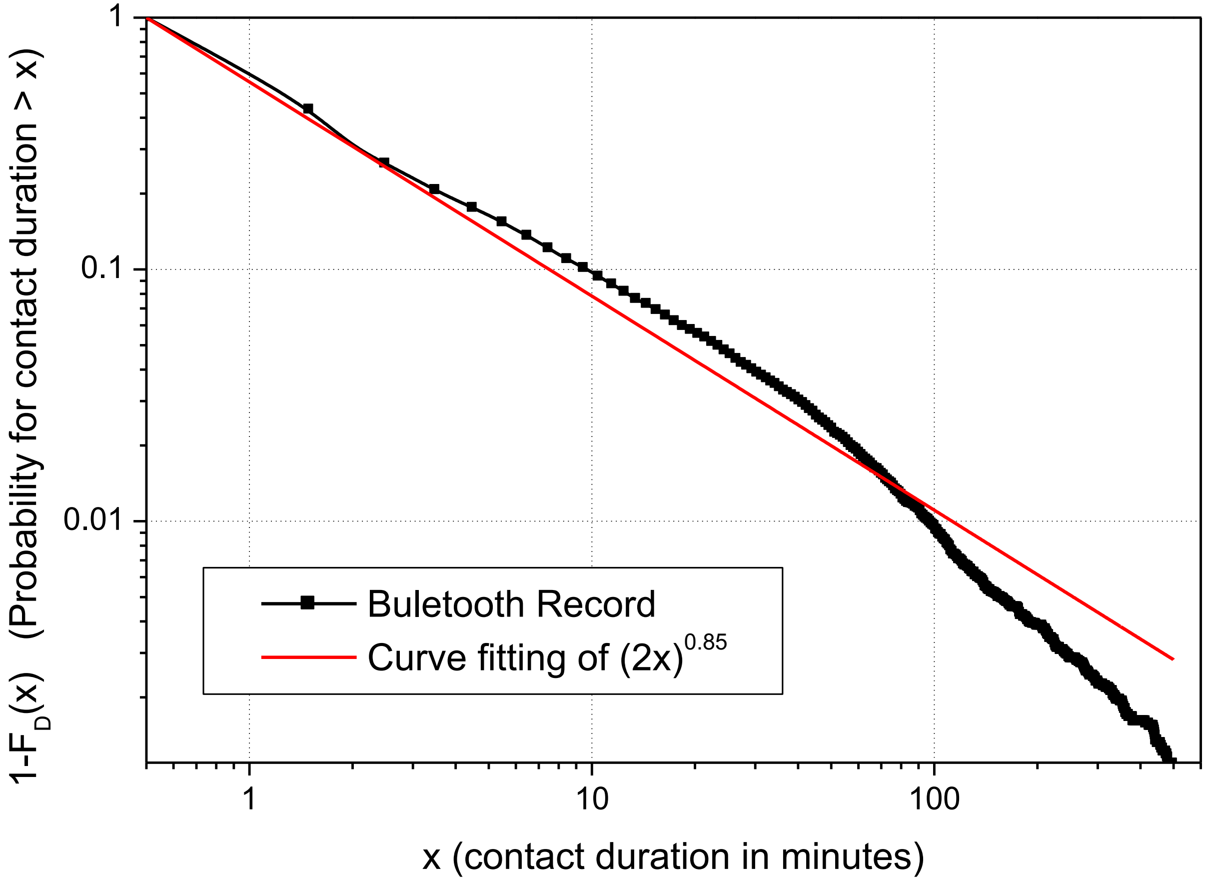
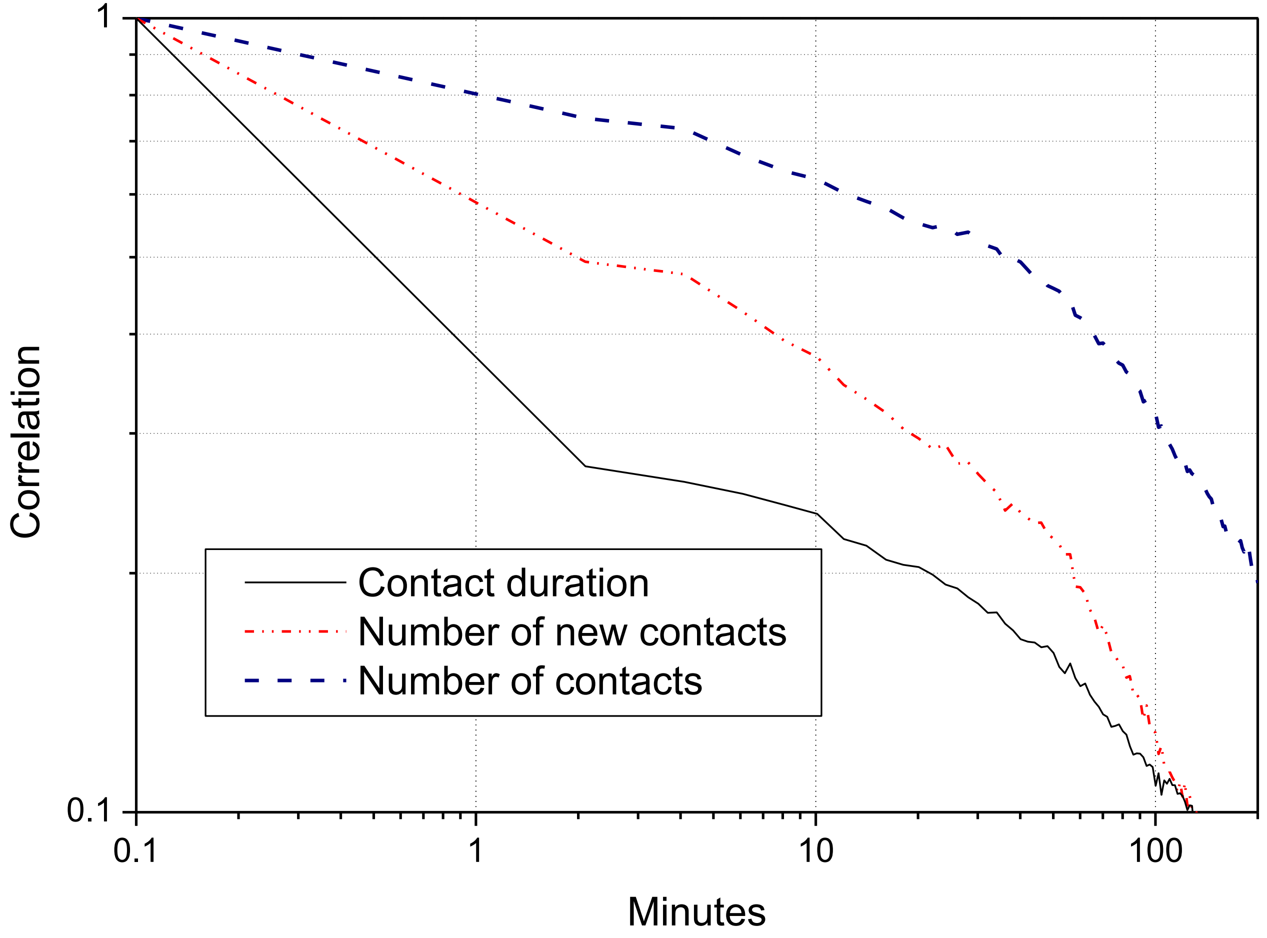
- Use Bluetooth Mobiles carried by 9 volunteers
- Discovery interval is 30 seconds, 24/7
- Collected data for 3 months, totally 12,332 unique devices are discovered
- Data can be used for both analysis and simulation

Contact duration distribution



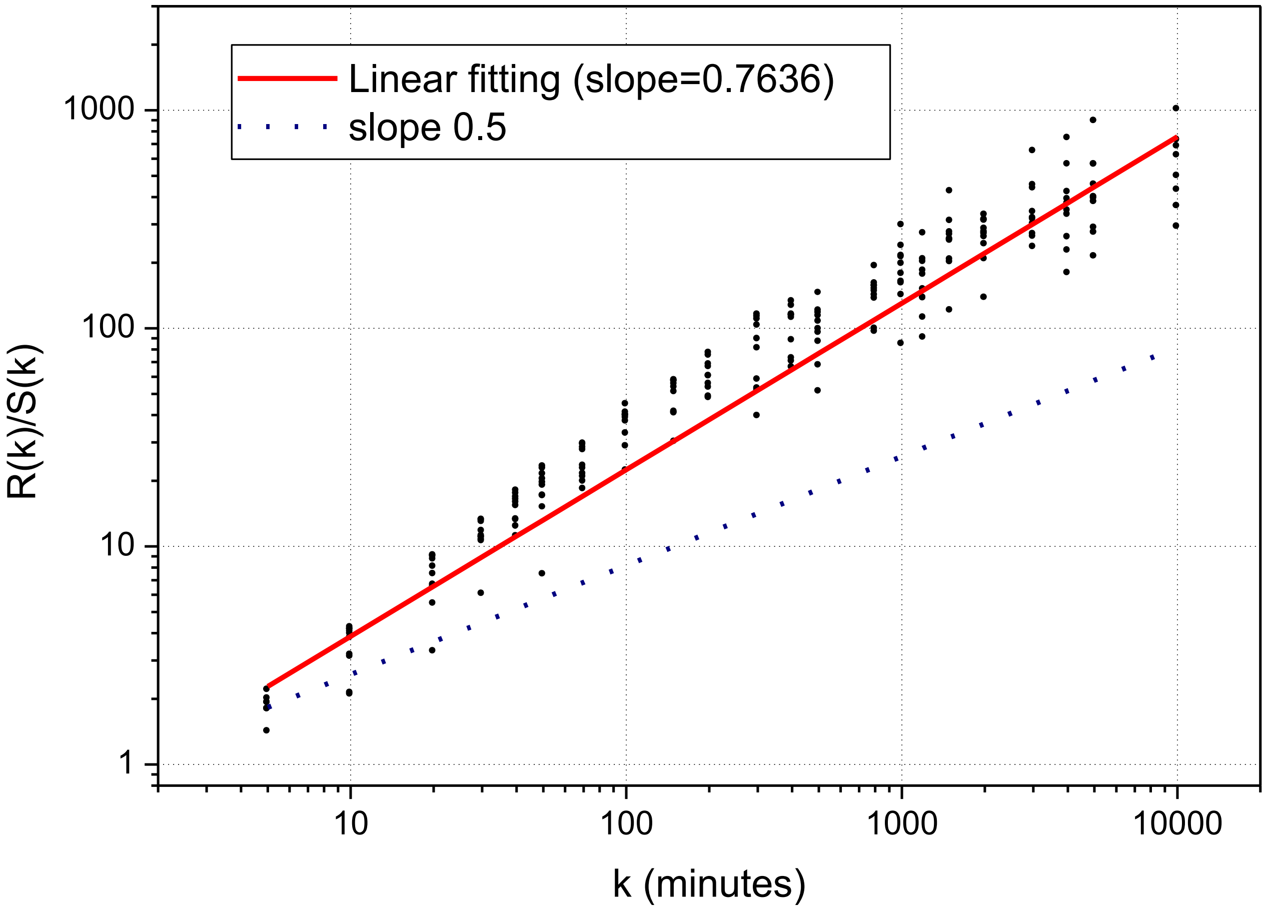
- **Contact duration distribution is Pareto with k=0.85**

Correlations



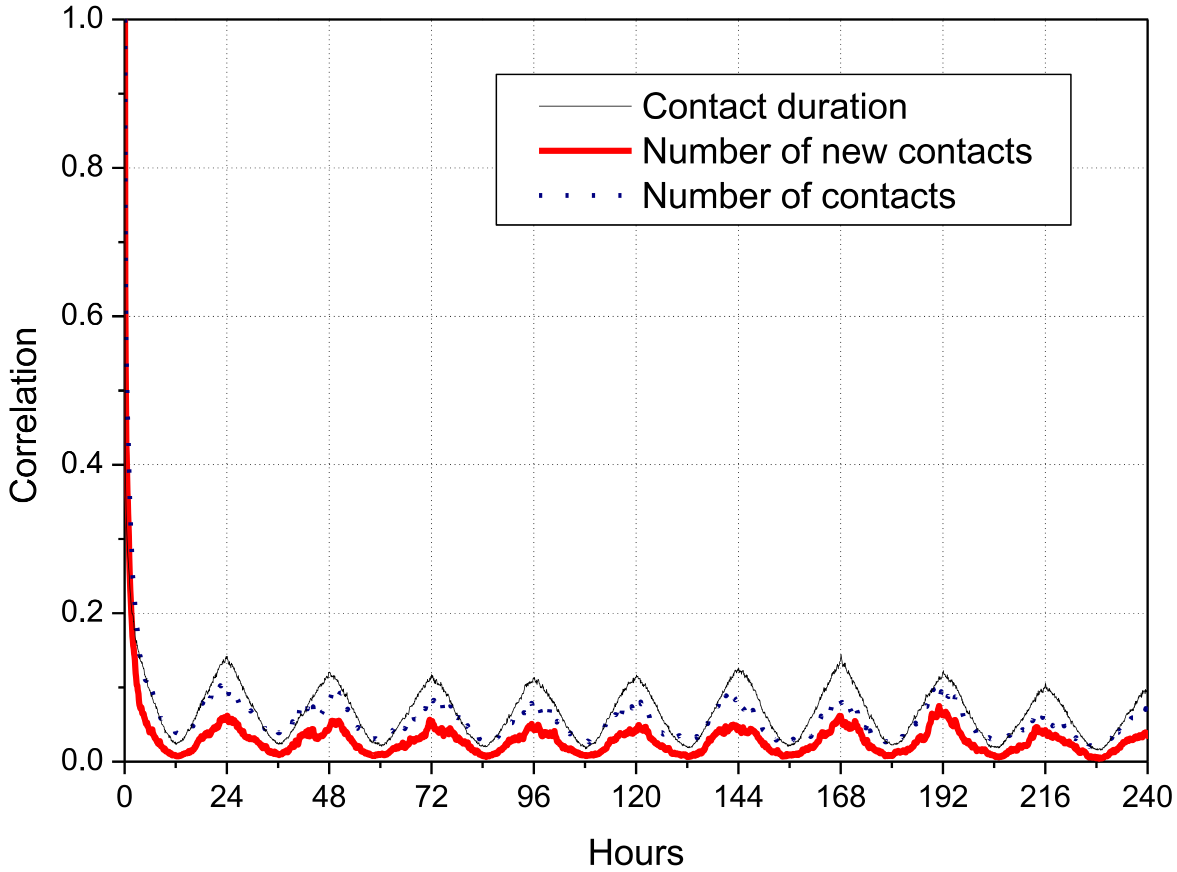
Correlation in short term is high → predictable arrival rate

Self similar contact patterns



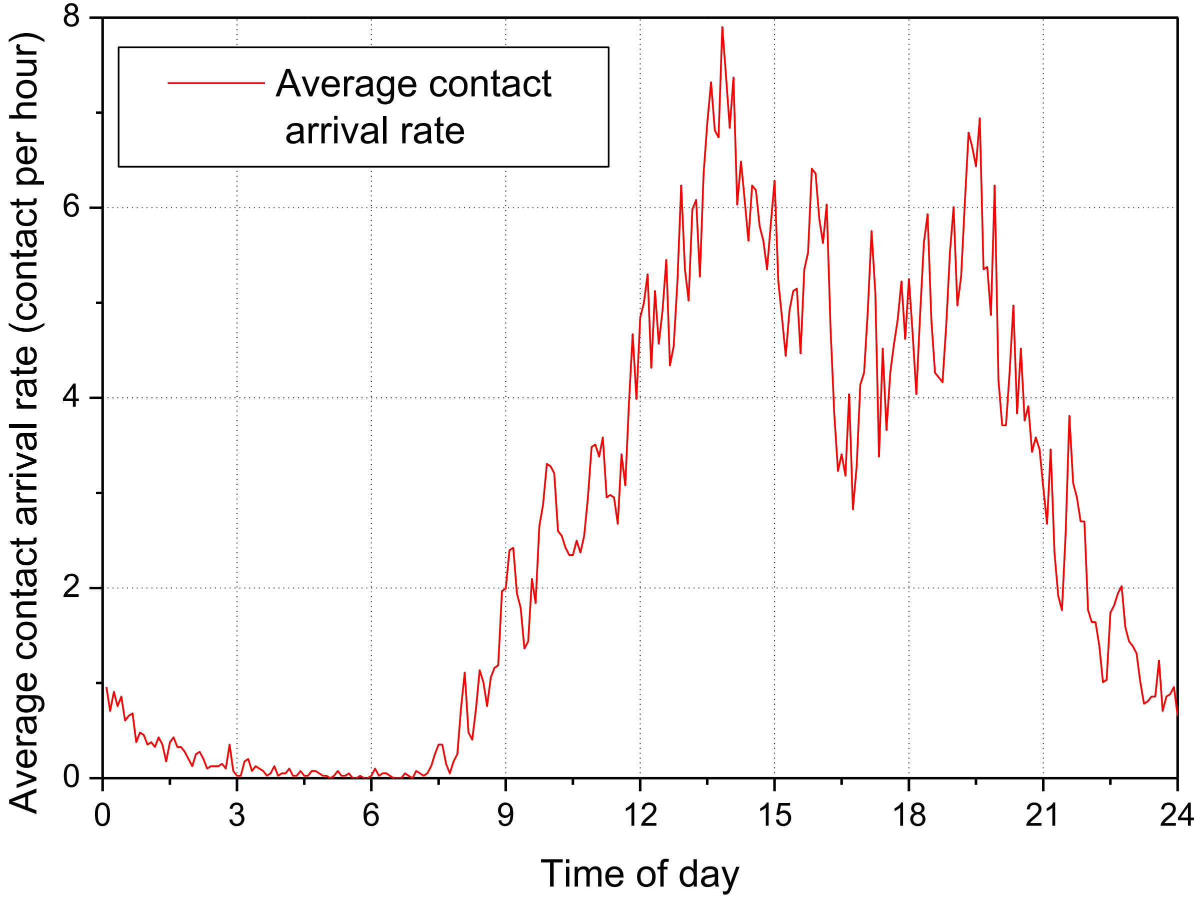
- **The R/S test shows the process is self similar**
- **Hurst parameter = 0.76**

Correlations



- **A 24 hours correlation period can be seen**

Varying contact arrival rate

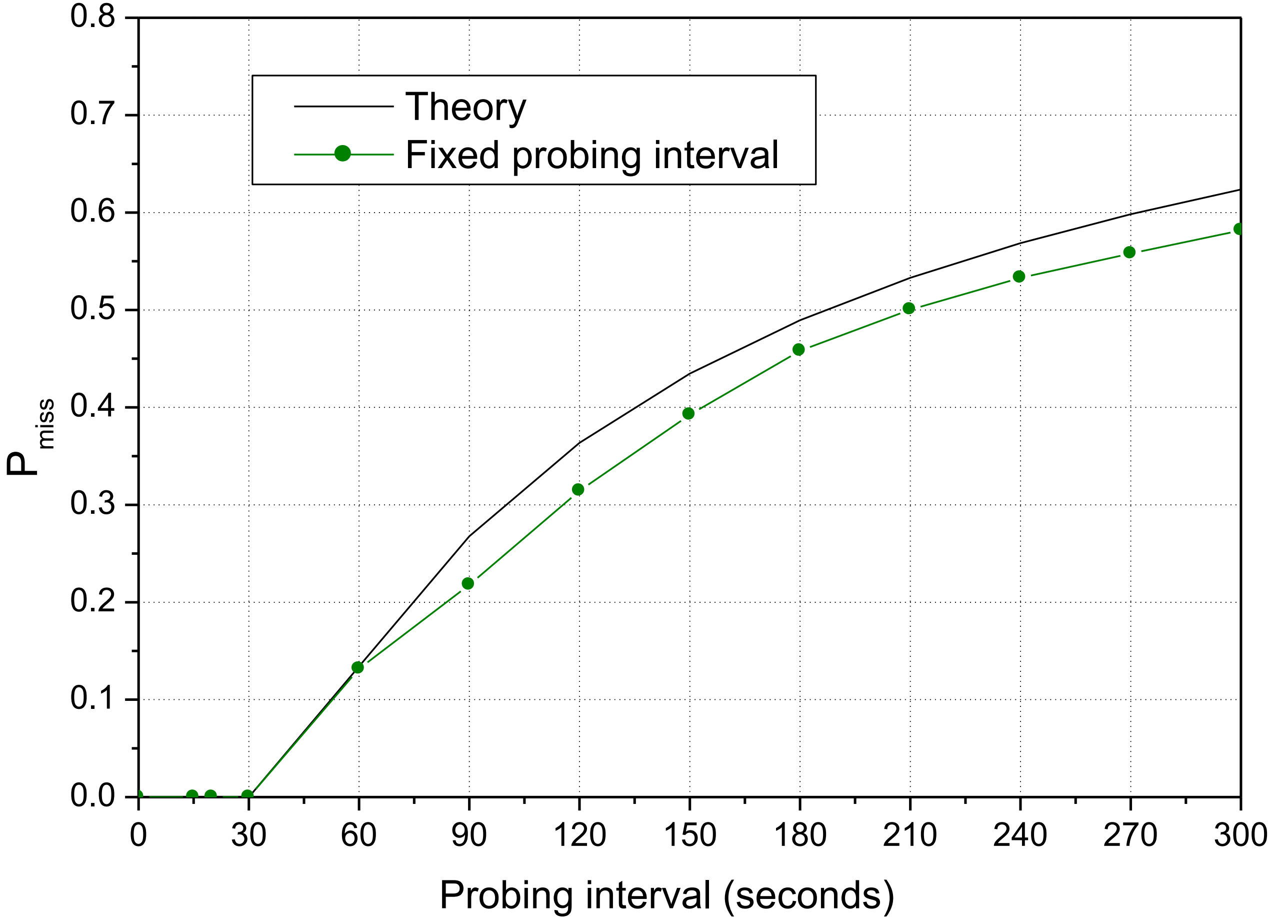


- **Obvious arrival rate change according to time of day**

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

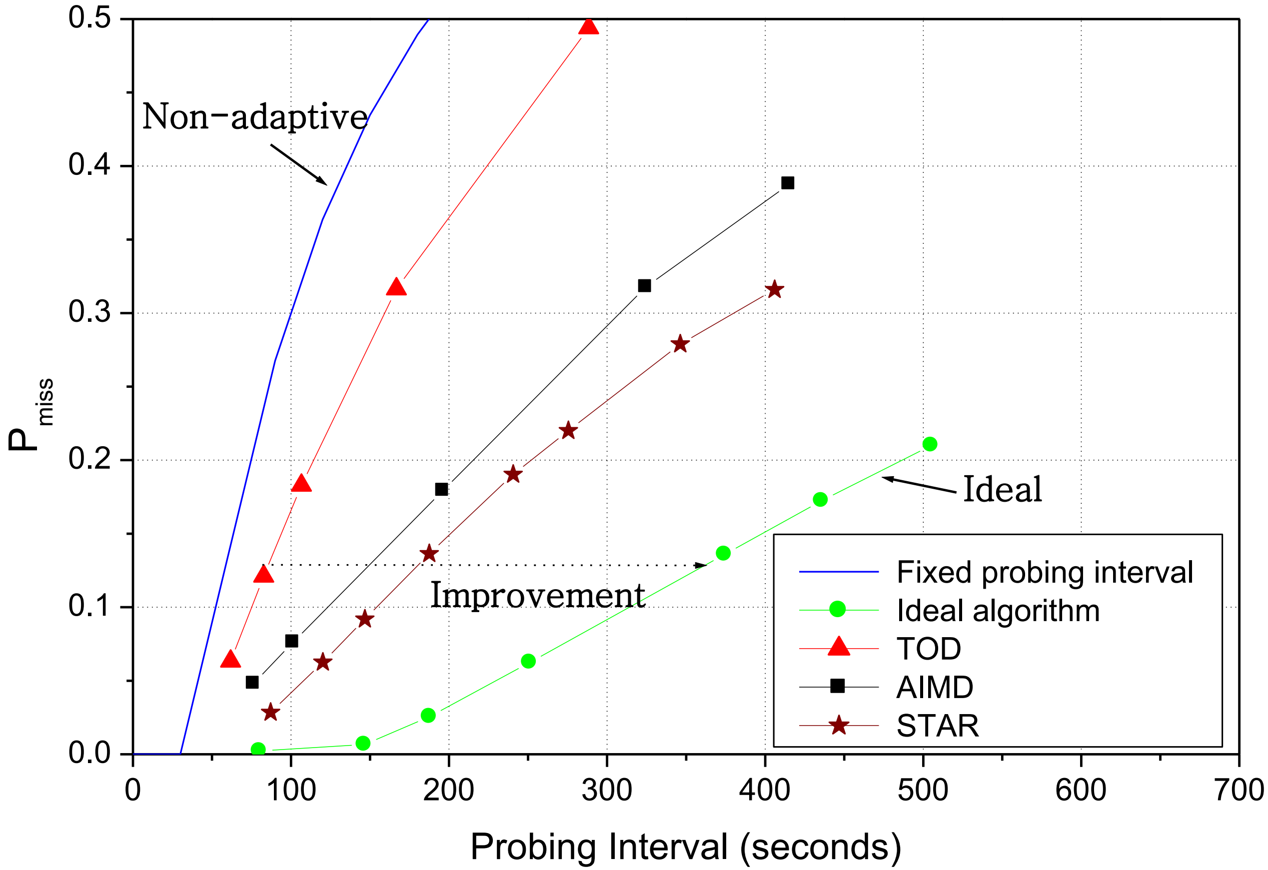


- **Constant probing rate, verify the theory**

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



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!

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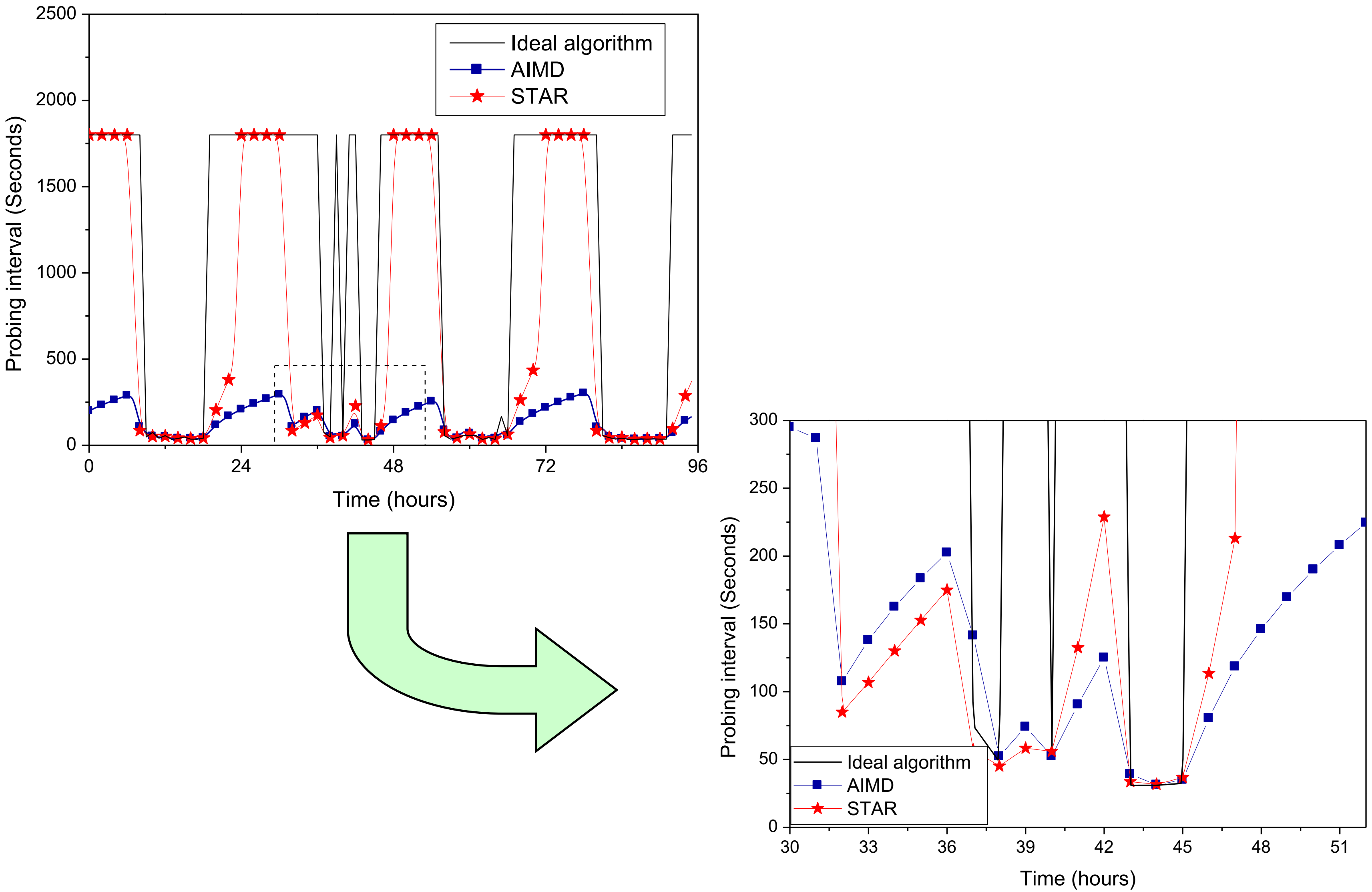
STAR

- 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



STAR with different *k*