Utilizing Distance Distribution in Determining Topological Characteristics of Multi-hop Wireless Networks

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• Link Probability
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Topological Characteristics

Degree: # of nodes in communication range

Average shortest path

Diameter: Longest shortest path

Link Probability
Degree
Average shortest path
Diameter,
Similarly for 3D

Are there any link? What is probability?
Importance of Topology Characteristics

• Performance of Protocol
  – Diameter
    • Bounds the maximum delay in message communication
  – Average Shortest Path
    • How efficient data transmission

• Security
  – Degree
    • Higher degree means higher node connectivity

• Generate more realistic topologies for Simulations
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Contribution

• Developed Analytical Formulas for 2D and 3D
  – Link Probability
  – Diameter
  – Average Shortest Path
  – Degree
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Link Probability

Probability of $d < r$

$$F_{2D} = r^2 \left( \frac{r^2}{2} - \frac{8r^3}{3} + \pi \right) \text{ where } 0 \leq r \leq 1$$

Distance distribution of unit cube between 0 and 1

$$f_{3D} = 4t^2 - 6\pi t^3 + 8t^4 - t^5$$

$$F_{3D} = \int_0^r f_{3D}(t) \, dt$$

$$F_{3D} = \frac{4\pi r^3}{3} - \frac{6\pi r^4}{4} + \frac{8r^5}{5} - \frac{r^6}{6} \text{ where } 0 \leq r \leq 1$$

Link probability or probability of $d < r$
Test of Link Probability

Link probability depends on only $r$ in both 2D and 3D
Test of Link Probability for less nodes

Link probability in 3D is less than 2D

Link probability depends on only $r$ in both 2D and 3D for less number of nodes
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Average Degree

\[ E_{ND}(n, r) = (n-1) F_{ND}(r) \]

\[ E_{2D}(n, r) = (n-1) \left( r^2 \left( \frac{r^2}{2} - \frac{8r}{3} + \pi \right) \right) \]

\[ E_{3D}(n, r) = (n-1) \left( \frac{4\pi r^3}{3} - \frac{6\pi r^4}{4} + \frac{8r^5}{5} - \frac{r^6}{6} \right) \]
Test for Average Degree

Exactly matches in 3D and 2D
Diameter

\[\text{Diameter}_{ND}(r) = \left\lfloor \frac{\sqrt{N}}{r} \right\rfloor\]

\[\text{Diameter}_{2D}(r) = \left\lfloor \frac{\sqrt{2}}{r} \right\rfloor\]

\[\text{Diameter}_{3D}(r) = \left\lfloor \frac{\sqrt{3}}{r} \right\rfloor\]
Test for Diameter

While r increased, approximation getting better.

Our approach more effective in 2D and
Average shortest path length

Expected Distance \( ND \) = \( \int_{0}^{\sqrt{N}} t f_{ND}(t) dt \) where \( f_{ND}(t) \) is distance pdf

\[
E_{hopND} \geq \frac{\text{Expected Distance}_{ND}}{r}
\]

\[
E_{hop2D} \geq \frac{0.52140543}{r}
\]

\[
E_{hop3D} \geq \frac{0.661707182}{r}
\]

0.52.. is expected distance in unit square

0.66.. is expected distance in unit cube
Test for Average shortest path

Approximation and simulation follow similar path

Avg. shortest of 3D higher than 2D
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Conclusion

• Developed Analytical Formulas for 2D and 3D
  – Link probability
  – Degree
  – Diameter
  – Average Shortest Path
• All formulas are verified by Simulation
• Studied effects of communication range and number of nodes to Topology in Networks
Future Work

• Develop formulas for some other characteristics
  – Coverage
  – Connectivity
  – Entropy (Randomness of a network)

• Study Topological Characteristic under motion environment in Wireless Network
Questions
References

References