Opportunistic Mobile Networks: Advances and Applications

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Solutions to Selected Exercises

Chapter 1

Origins and Characteristics

Exercise 1.1

Discuss some of the fundamental differences between the Internet and DTN.

Exercise 1.2

Suppose that an autonomous vehicle has been dropped on the surface of Mars from a satellite, which itself is orbiting Mars. The vehicle can communicate with the satellite and the satellite can communicate with a station on the Earth, but they are never in the line of sight altogether. Suggest a mechanism for data transmission from the vehicle to the Earth station.

Answer of exercise 1.2

The satellite stores data received from the autonomous vehicle when they are in line of sight. The satellite transmits the stored data to the Earth station when they two come in line of sight.

Exercise 1.3

Why underwater communications use acoustic waves in contrast to electromagnetic waves used terrestrially?

Answer of exercise 1.3

Electromagnetic waves, being of high frequency, are easily absorbed by water. Acoustic waves, on the other hand, have lower frequency, and therefore, can travel a longer distance in underwater environments.

Exercise 1.4

How message replication is different from message forwarding?

Answer of exercise 1.4

Unlike forwarding, when a message is replicated, the transmitting node itself retains the message after it has been successfully transmitted to the receiving node.

Exercise 1.5

What is meant by the "store-carry-and-forward" mechanism of message transmission?

Exercise 1.6

How the aspects of "cooperation" are different from "trust" and "reputation"?

Answer of exercise 1.6

Cooperation, trust, and reputation are often closely related aspects. However, when we talk about cooperation, we usually deal with selfish or non-cooperative nodes. For example, an exploiter may receive message from other nodes, but never replicate them further. On the other hand, aspects of trust and reputation arise in the presence of malicious nodes, in general. For instance, similar to an exploiting node, a malicious node can drop messages, but at the same time, it can claim itself as benevolent to the other nodes. Trust and reputation schemes help to identify to what extent such a claim made by any node is valid.

Exercise 1.7

Why human mobility is a fundamental aspect in PSNs/OMNs?

Answer of exercise 1.7

A disconnected network, which is stationary, would perhaps remain disconnected forever. However, it is mobility of the nodes that bring them in proximity of one another, which results in communication opportunities. In PSNs/OMNs, where the devices are carried by human users, contacts take place as people move around.

Exercise 1.8

What is a buffer management scheme? Give example of some such typical schemes in the context of DTNs.

Answer of exercise 1.8

Nodes have finite buffer space for storing messages. When the buffer is filled up, or the available space is less than the size of the incoming message, one or more message(s) must be dropped to make space for the new one. A buffer management scheme is a set of policies that dictates which message from the buffer be dropped in such circumstances. A few typical examples are:

- Drop Oldest: Drop the message having minimum TTL
- Drop Last: Drop the recently received message
- N-Drop: Drop a message that has been forwarded N times
- Drop Largest: Drop the message having the largest size

- Evict Most Forwarded First: Drop the message that has been forwarded the maximum number of times

You may refer to the following for further details on these policies.

- Y. Li, L. Zhao, Z. Liu, and Q. Liu, "N-Drop: congestion control strategy under epidemic routing in DTN," in Proc. of IWCMC 2009, USA, pp. 457-460.
- A. Lindgren and K. S. Phanse, "Evaluation of Queuing Policies and Forwarding Strategies for Routing in Intermittently Connected Networks," in Proc. of COMSWARE 2006, New Delhi, pp. 1-10.

Exercise 1.9

Why is congestion bad for a network? Discuss some congestion avoidance and control schemes for DTNs.

Chapter 2

Delay Tolerant Routing and Applications

Exercise 2.1

Write down some metrics relevant to the evaluation of routing protocols. Should these metrics be maximized or minimized to obtain a better performance? Why routing overhead is typically considered in DTNs, but not in the traditional networks, for example, Internet and mobile ad hoc networks?

Answer of exercise 2.1

Traditional networks involve single-copy packet routing. A given packet is forwarded to the next hop of the routing path. Thus, such networks do not suffer from the overhead caused by multiple copies of a packet/message.

Exercise 2.2

Consider the following contact pattern among a set of five nodes:

$\mathcal{C} = \{(A, B, 10), (A, C, 14), (C, D, 16), (B, D, 19), (D, E, 22)\}$,

where $(X, Y, t) \in \mathcal{C}$ indicates that nodes X and Y encountered one another at the time instant t. Further, let the set of messages created be $M = \{(m_1, A, 12), (m_2, B, 15), (m_3, C, 16)\}$, where $(m, X, t) \in M$ indicates that a message with ID m was created by the node X at the time instant t.

Which messages would be carried by the node E after time instant $t = 23$ when Epidemic and Spray-and-Wait routing protocols are used? Assume that each contact between a pair of nodes lasted for one time unit. Also, assume that SnW is used in binary mode with initial number of copies of a message as 4.

Answer of exercise 2.2

The sequence of message replications over time when Epidemic routing is used is shown below.

	$t = 14$	$t = 16$	$t = 19$	$t = 22$
A	m_1			
B		m_2	m_1, m_2, m_3	
C	m_1	m_1, m_3		
D		m_1, m_3	m_1, m_2, m_3	
E				m_1, m_2, m_3

Therefore, at $t = 23$, node E would have the following messages: m_1, m_2, m_3. The replication sequence on using SnW is shown below. The numbers inside brackets indicate the contemporary number of copies of the corresponding messages carried by nodes.

	$t = 14$	$t = 16$	$t = 19$	$t = 22$
A	$m_1(2)$			
B		$m_2(4)$	$m_2(2), m_3(1)$	
C	$m_1(2)$	$m_1(1), m_3(2)$		
D		$m_1(1), m_3(2)$	$m_1(1), m_2(2), m_3(1)$	$m_1(1), m_2(1), m_3(1)$
E				$m_2(1)$

So, when SnW is used, node E ends up with a single copy of the message m_2. The reader is advised to verify from the above tabulation that the total number of copies of any message at any time instant is 4.

Exercise 2.3

What are the advantages of SnF over SnW? What similarity does the Spray and Focus and PRoPHET protocols have?

Answer of exercise 2.3

Both SnF and PRoPHET capture transitivity aspect of contact among the nodes.

Exercise 2.4

Support or reject the following claim with justifications.

When the initial number of copies of a message is infinitely large, SnW degenerates into the Epidemic routing protocol. This is true irrespective of whether or not binary mode of spraying is used.

Answer of exercise 2.4

This is true when binary mode of replication is used. This is because, after a replication of a message, both the transmitting and receiving nodes would have infinitely large number of copies of the message. Collectively, there would be no replication limit upon any message, which essentially reduces SnW to Epidemic routing.

If non-binary mode is used, any receiving node receives only a single copy of a message, and therefore, cannot replicate it any further. However, a source node is still capable of unlimited replication of messages created by it. This is unlike the Epidemic routing protocol.

Exercise 2.5

Assume that the nodes in a network move with a constant speed of 5 m/s. Suppose that the nodes A and j had their last encounter at $t = 1$ second, and the nodes B and j recently encountered at $t = 2$ second. Consider that at $t = 6$ second, nodes A and B come in contact, and the distance between them is 10 m. According to the Spray and Focus algorithm, what would be the value of $\tau_A(j)$ after this contact?

Answer of exercise 2.5

We have, $\tau_A(j) = 6-1 = 5$, and $\tau_B(j) = 6-2 = 4$. Also, $t(d_{AB}) = 10/5 = 2$. Now, $\tau_B(j) + t(d_{AB}) = 4 + 2 = 6 > \tau_A(j)$. So the value of $\tau_A(j)$ remains 5.

Once again, we remind the reader to keep in mind the aspects discussed in the context of Example 2.2 in the book while working with SnF.

Exercise 2.6

Assume that the delivery predictabilities between two pairs of nodes (using PRoPHET) just before the time instant t be $P(A, B) = 0.6$ and $P(B, C) = 0.7$, respectively. Further assume that $P(A, C)_{old}$ is 0.5. At time t the two nodes A and B come in contact. What would be the value of $P(A, C)$ after 120 seconds from the time instant t if the nodes A and B did not had any subsequent encounter? Assume that each time unit comprises of 60 seconds.

Answer of exercise 2.6

1. Update $P(A, B)$ to: $P(A, B)_{old} + (1 - P(A, B)_{old}) \times P_{init} = 0.6 + (1 - 0.6) \times 0.75 = 0.9$

2. Update $P(A, C)$ to: $P(A, C)_{old} + (1 - P(A, C)_{old}) \times P(A, B) \times P(B, C) \times \beta = 0.5 + 0.5 \times 0.9 \times 0.7 \times 0.25 = 0.578$

3. Age $P(A, C)$ to: $P(A, C)_{old} \times \gamma^2 = 0.578 \times 0.998^2 = 0.575$

Exercise 2.7

Consider some well known algorithms for finding shortest path in a graph (for example, those proposed by Dijkstra and Floyd-Warshall). What is the challenge in their direct adaptation to OMNs?

Answer of exercise 2.7

In Dijkstra's algorithm, for example, a node is aware of the global network topology – the number of nodes in a network, existing links among them, and cost of all such links. Information about the link costs serve as an input to the shortest path computation algorithm. However, in OMNs, the nodes usually do not have such a global view of the network, which prevents a direct use of traditional shortest path algorithms. The transitivity equation from the Bellman-Ford algorithm, however, is often used by many routing protocols, since such local information is typically available.

Exercise 2.8

What is a Bloom filter? How Bloom filters can be useful in the context of the vaccine scheme used with Epidemic (or other) routing protocol?

Exercise 2.9

Suppose that the nodes in an OMN use SnW routing protocol. Let L be a constant that indicates the initial number of copies of any message created in the network. Prove that the overhead ratio in the OMN cannot be greater than L.

Answer of exercise 2.9

Let the number of messages that has been successfully delivered be n. In the worst case, there would be L replica per message in the OMN. Then the overhead ratio is computed as $(nL - n)/n = L - 1 < L$.

Chapter 3

A Developer's Guide to the ONE Simulator

Exercise 3.1

In Listing 3.13, why a call to the `advanceWorld(1)` method is required in line number 29? What would happen if that call is omitted? What would happen if the time argument is changed to 10?

Answer of exercise 3.1

The `advanceWorld(n)` is an easy way to invoke two methods serially: `clock.advance(n)` and `updateAllNodes()`. The first method advances the simulation clock by n time units, whereas the other method updates all the nodes. A node update, in turn, updates the contemporary state of connections and message transfers. In other words, message transfer essentially progresses with such updates. If the aforementioned method invocation was ignored, the destination node would not have completed receiving the message, which would lead all subsequent assertions to fail.

Exercise 3.2

Explain the difference between *step over* and *step into* in the process of debugging code.

Answer of exercise 3.2

The difference is better understood when the instruction at the breakpoint, and the subsequent ones, involve invocation of other methods rather than primitive operations. With *step into*, debugging would lead into tracing of all instructions starting from the current one – whether in the same method, class, or other – until the last one is traced after which, the control returns to execute the next instruction from where the tracing had started. One may compare it with a "depth-first search" strategy. However, with *step over*, the sequence of debugging does not go deeper – it only moves over the instructions of the current method until it passes to somewhere else. Try these techniques over a loop and a nested method call for a concrete idea.

Exercise 3.3

In the domain of version control, *branching* is an quintessential process. A branch represents a parallel line of development. Write the command to create a branch using Git. How would you switch to the newly created branch so that changes are made to the new branch and not to the original branch? Note that in Git, the default branch is called *master*.

Answer of exercise 3.3

```
$ # List the current branches; by default, there is only the master ↩
    branch
$ git branch
* master
$ # Create a new branch
$ git branch testing
$ # Switch to the new branch
$ git checkout testing
$ git branch
  master
* testing
```

Exercise 3.4

Why is unit testing a better approach than performing actual network simulations?

Answer of exercise 3.4

A network simulation is a complex process involving lots of nodes, their behaviors, and interactions. Even if such a simulation executes successfully and produces some results, by merely looking at the output it is difficult to tell whether or not the implementation reflected correct or desired logic. An alternative is to debug the application. However, since there would be numerous method call, it might become cumbersome to locate the actual position of execution of the desired behavior, and verify its effect. Moreover, depending upon the scenario, a simulation may take a long time to finish.

On the other hand, it requires a little effort to write unit test cases for the protocols developed. However, once such a test case is written, one can easily pin point whether or not the desired behavior is reflected in the code. Additionally, when a new protocol is shipped, having associated unit test cases allow the users to verify its advertised behavior.

Exercise 3.5

Consider that you are writing unit test cases using JUnit for a set of routing protocols. Explain why would you have your test cases extend the `AbstractRouterTest` class rather than using JUnit annotations?

Answer of exercise 3.5

The `AbstractRouterTest` class already provides a bunch of member variables and utility methods that are useful for writing a new test case. However, if the annotations-based approach is used, one would require to manage all such bookkeeping by himself/herself.

Chapter 4

Emerging Sensing Paradigms and Intelligence in Networks

Exercise 4.1

What is the difference between participatory and opportunistic sensing? Nike+ Sportwatch GPS[1] measures, among other things, the distance that you have ran. Discuss whether such sensing is participatory or opportunistic.

Answer of exercise 4.1

The Sportwatch acts a sensor, which determines the distance based on the starting and finishing locations reported by GPS records. This is an example of participatory sensing. Here, mobility is not creating an opportunity for sensing. Rather the goal is to measure mobility itself.

Exercise 4.2

What is a proximity sensor? Why do smartphones typically have such a sensor?

Answer of exercise 4.2

A proximity sensor can detect the presence of any object nearby it without involving any physical contact process.

Modern smartphones are usually equipped with such sensors. When we make a call and take the phone near our ear, the sensor detects the proximity, and disables the touch screen in order to prevent any accidental touch event while a call is in progress.

Exercise 4.3

[1] `https://secure-nikeplus.nike.com/plus/products/sport_watch/`

Discuss how Twitter can act as a "social sensor".

Exercise 4.4

What is an agent? How are agent-based systems useful?

Exercise 4.5

What is situation awareness? Discuss the three levels of situation awareness relevant to an aircraft pilot.

Exercise 4.6

Suppose that you have a smartphone that has an app, which advises you the optimum time to withdraw cash from a nearby ATM center. Now, you are not always available to access the ATM, for example, you might be in the office or university. Again, if it is too hot or cold outside or, if it is raining heavily, you are unlikely to go. Moreover, the app should disable all notification when you are sleeping at night. In this scenario, what are the different inputs — from sensors or otherwise — the smartphone can provide to that app to make it context aware?

Answer of exercise 4.6

Various sensors can be used in this process as described below.

- GPS: To get the current location
- Clock: To get the current time
- Light sensor: To detect the surrounding luminosity; useful to identify if the user is sleeping at night, when the surroundings would be dark
- Temperature sensor or Internet connection: To identify the atmospheric conditions outside

Exercise 4.7

How are MOONs different from OMNs?

Answer of exercise 4.7

By definition, a MOON is formed among the devices carried by human users. Moreover, in MOONs, aspects of human users can fundamentally influence the ongoing network communications.

Exercise 4.8

In Figure 4.4, which are the 2-right zones of zones 8 and 9?

Answer of exercise 4.8

The 2-right zones of zone 8 are 9 and 4; of zone 9 is 4.

Chapter 5

Aspects of Human Emotions and Networks

Exercise 5.1

What are the basic emotions considered in Ekman's and Plutchik's models?

Exercise 5.2

Draw a Markov chain depicting the basic emotions from Ekman's model. Show all the state transitions.

Exercise 5.3

List all the combinations of basic emotions that give rise to secondary emotions in Plutchik's model.

Answer of exercise 5.3

Refer to Figure 5.1.

Exercise 5.4

How are emotion and mood distinguished?

Answer of exercise 5.4

The terms emotion and mood are closely related with subtle differences. Emotions are generated in response to specific events. Mood, on the other hand, is often not related to particular events, but to a general context. Emotions exist for shorter time durations, whereas moods can prevail for a long duration for example, hours and days. Moreover, as we looked in Ekman's model, emotions often are associated with distinct facial expressions, but moods usually are not. For further details, you may look at the following book chapter.

D. Hume, "Emotions and Moods," in *Organizational Behavior*. Pearson, pp. 258–297.

Exercise 5.5

How the physiological signals can be classified based on the nervous systems?

Answer of exercise 5.5

Please refer to the following article:

L. Li and J.-h. Chen, "Emotion recognition using physiological signals," in *Advances in Artificial Reality and Tele-Existence*, ser. Lecture Notes in Computer Science, Z. Pan, A. Cheok, M. Haller, R. Lau, H. Saito, and R. Liang, Eds. Springer Berlin Heidelberg, 2006, vol. 4282, pp. 437446. [Online]. Available: http://dx.doi.org/10.1007/11941354 44

Exercise 5.6

List a few physiological signals and discuss what they represent. Also, list some sensors that can measure such signals.

Answer of exercise 5.6

- Skin conductance (also referred to as electrodermal activity or Galvanic skin response): Sweating, in general, increases in response to strong emotions experienced by people, which causes change in skin conductance. GSR sensors, usually in the form of two small straps worn around fingers, can measure changes in skin conductance, and therefore, the underlying emotional response.

- Skin temperature: Arguably, all of us familiar with thermometers used to measure body temperature. Today, different sensor-based solutions are also available that provide similar measurements.

- Heart rate: Electrocardiogram (ECG) can be used to measure heart rate of a person.

- Respiration pattern: As we breathe in and out, the movement of the walls of our chest and abdomen changes. A respiratory inductance plethysmograph, typically a belt worn around the chest, can measure such patterns.

- Airflow: The rate of air flowing through node can itself be measured with airflow sensors, which consists of two little prongs placed in the nostril.

- Blood oxygen level: Saturation of oxygen level in blood changes with different activities. Pulse oximeter devices can be used to measure such oxygen saturation level. It is developed in the form of a clip that can be attached to a finger. Its working principle is based on the fact that the amount of light absorbed by blood depends upon the hemoglobin level and the type of light used.

Exercise 5.7

What is emotion contagion?

Answer of exercise 5.7

Emotion contagion is the process where emotions of some people affect the emotions of others. For example, when a person in a group of people starts laughing, others often start laughing too. This phenomena is somewhat similar to contagious diseases – an affected person affects others. Emotion contagion has been observed for both positive and negative emotions.

Exercise 5.8

Consider the following emotion intensity vector, $\mathbf{e} = \big(0.3\ 0.2\ 0.3\big)$, and the coefficients of decay of basic emotions, $\mathbf{a} = \big(0.0025\ 0.0010\ 0.0015\big)$. What would be the dominant emotion after 10 units of time?

Answer of exercise 5.8

After 10 units of time, intensities of the three emotions, respectively, become:

1. $0.3 \times exp(-0.0025 \times 10) = 0.2925$
2. $0.2 \times exp(-0.0010 \times 10) = 0.1980$
3. $0.3 \times exp(-0.0015 \times 10) = 0.2955$

Therefore, the third emotion becomes dominant.

Chapter 6

Evolutionary Game in Wireless Networks

Exercise 6.1

How evolutionary game theory is different from classical game theory?

Exercise 6.2

What are the differences with respect to players in CGT and EGT?

Answer of exercise 6.2

See the box at the end of Section 6.1.

Exercise 6.3

What is replicator dynamics?

Exercise 6.4

When does a strategy become an evolutionary stable strategy?

Exercise 6.5

What is Simpson's paradox? Illustrate with an example.

Exercise 6.6

Consider a pairwise population game among players with action set $A = \{F, R\}$ and payoffs $\pi(F, F) = 0$, $\pi(F, R) = 2$, $\pi(R, F) = -1$, and $\pi(R, R) = 1$. Deduce the replicator dynamics equations for this game and find all the fixed points.

Exercise 6.7

Consider a payoff matrix as shown in the Table below. Find out whether the fixed point is asymptotically stable or unstable.

		A		
		C	E	I
B	C	2, 2	-3, 1	2, -1
	E	1, -3	1, 1	-1, 1
	I	-1, 2	1, -1	0, 0

Chapter 7

Enforcing Cooperation in OMNs

Exercise 7.1

Let us consider four broad areas in OMNs – multicasting, cooperation, trust, and privacy. Suppose that, in the year 2014, the number of research works focused on these four areas were 10, 75, 40, and 30, respectively. Whereas, in 2015, these numbers were 5, 60, 25, ad 45. What is the cosine similarity of research focus between these two years?

Answer of exercise 7.1

Let us consider two vectors, $\mathbf{A} = (10, 75, 40, 10)$ and $\mathbf{B} = (5, 60, 25, 45)$. The cosine similarity between these two vectors is given by $\cos\theta = \frac{\mathbf{A}\cdot\mathbf{B}}{AB} = \frac{10\times5+75\times60+40\times25+10\times45}{\sqrt{10^2+75^2+40^2+10^2}\sqrt{5^2+60^2+25^2+45^2}} \approx 0.88$. Since this value is close to 1, research focus in the two concerned years had strong similarity.

Exercise 7.2

What is sybil attack?

Exercise 7.3

What is a contact graph? What are edge insertion and removal attacks?

Exercise 7.4

Discuss one of the challenges of using incentive-based schemes in OMNs.

Answer of exercise 7.4

In credit-based schemes, a node has to be provided with credits once it has helped others in delivering their messages. However, due to the inherent characteristics of OMNs, contacts among the nodes are rare and often includes long time gaps. As a consequence, unlike other networks such as, MANETS, where nodes have end-to-end connections, in OMNs, it is difficult for a source node to trace the helping node and subsequently reward it.

Exercise 7.5

What is a watchdog? How is this concept used in the context of network cooperation?

Exercise 7.6

Let us focus on a single node say, X, in an OMN, which is using DISCUSS. Suppose that $\Psi(t) = \{\Psi_C = 15, \Psi_E = 10, \Psi_I = 5\}$. What are the weighted factors for each group? Also, consider that $\alpha_C = 0.5$, $\alpha_E = 0.8$, and $\alpha_I = 0.3$. What is the most successful strategy of the OMN as determined by X? If the strategy of X at the beginning of the current generation was cooperate, would there be any change in its strategy after this generation? Explain.

Answer of exercise 7.6

The weighted factors for the groups cooperators, exploiters, and isolators are as follows.

$$\begin{aligned}
\omega_C &= \frac{15}{15+10+5} = 15/30 \\
\omega_E &= \frac{10}{15+10+5} = 10/30 \\
\omega_I &= \frac{5}{15+10+5} = 5/30
\end{aligned}$$

Now, weighted average delivery ratios are determined as:

$$\begin{aligned}
\gamma_C &= \alpha_C \times \omega_C = 0.5 \times 15/30 = 7.5/30 \\
\gamma_E &= \alpha_E \times \omega_E = 0.8 \times 10/30 = 8/30 \\
\gamma_I &= \alpha_I \times \omega_I = 0.3 \times 5/30 = 1.5/30
\end{aligned}$$

Since γ_E has the maximum value, exploitation is the most successful strategy. Consequently, the node would change its strategy from cooperation to exploitation at the end of the current generation.

Chapter 8

Heterogeneity in OMNs

Exercise 8.1

Let ω and ω', respectively, be the message overhead ratio obtained using a specific routing protocol in a homogeneous and heterogeneous OMN. Then, $\omega' \leq \omega$. Explain why. Assume that all messages have infinite TTL and were generated within a certain time period, and the buffers of the nodes have unlimited storage capacity.

Answer of exercise 8.1

Since all the messages were generated within a specific time period, given infinitely long time, all of them would be delivered to their corresponding destination nodes. Such delivery could be direct, where the source node itself delivers a message to the destination node. Otherwise, they would be delivered via other intermediate nodes through message replication. However, in a heterogeneous network, the scope of such replications would be less. This would result in lower overhead ratio in heterogeneous networks as compared to a homogeneous one. Also note that with the assumption of sufficiently long operation period, all messages can be delivered in both type of networks. This makes the denominator in the definition of overhead ratio equal in both the scenarios.

Exercise 8.2

Apart from the different types of heterogeneity discussed in this Chapter, what other aspects of heterogeneity can arise in a network? Which of them would affect the network performance? Which of them would not?

Answer of exercise 8.2

Heterogeneity in screen size and computing speed of the devices, in general, does not affect network performance although they might be relevant for other applications/services.

Exercise 8.3

Inter-contact times in DTNs are sometimes found to be exponentially distributed, and sometimes follow Pareto distribution. Characterize the underlying human contact process that leads to such distributions.

Exercise 8.4

How does the semi-log plot of the complementary CDF (CCDF) of an exponential distribution look like? How about the log-log plot of CCDF of a power law distribution? Explain using the expressions for their respective CCDFs.

Answer of exercise 8.4

The CCDF of an exponentially distributed random variable X is given by $y = F(X > x) = exp(-\lambda x)$. Taking logarithm on both sides we get, $\ln y = -\lambda x$. Let $y' = \ln y$. Then, $y' = -\lambda x$, which is the equation of a straight line. Therefore, on a semi-log plot, where the x-axis is linear and the y-axis is logarithmic, the CCDF of an exponentially distributed variable would ideally appear as a straight line.

A similar analysis would show that the CCDF of a power law distribution would appear as a straight line in a log-log plot. However, it should be carefully noted that a linear curve in a log-log plot does not necessarily indicate that the process follows power law. Other distributions, too, can lead to such a plot.

Exercise 8.5

Given a set of observations from a Pareto distribution, estimate its shape parameter, α, using the maximum likelihood method.

Answer of exercise 8.5

You may look at `https://en.wikipedia.org/wiki/Pareto_distribution#Parameter_estimation`

http://www.springer.com/978-3-319-29029-4

Opportunistic Mobile Networks
Advances and Applications
Misra, S.; Saha, B.K.; Pal, S.
2016, XXXII, 303 p. 66 illus., 3 illus. in color., Hardcover
ISBN: 978-3-319-29029-4