Source: **Motorola**
Title: **System Level Channel Model**
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1. SUMMARY

This contribution presents an approach to modeling a spatio-temporal channel at the system level for the purpose of evaluating multi-antenna techniques. Values obtained from measurements are used to define the ranges for selected parameters used in the model. A procedure for generating and using the model is provided. Illustrations from a simulated model are shown which verifies the operating assumptions given.

2. ANGLE OF DEPARTURE

In [1] a description of measurements of Azimuth Spread (AS = σ_{PAS}) and Node-B Angle of Arrival (AoA) is given. This reference indicates that for a given value of AS, the AoA is a Gaussian distribution in angle as shown in Figure 1. The AS is a power weighted term, and related to the AoA sigma, which describes the distribution of angle occurrence. As discussed in [1], the sigmas are proportional such that σ_{AoA} is approximately $1.3\sigma_{PAS}$ (the approximate average for three different data sets.) The proposed model follows these expected relationships. In the figures and text below, the AoA is changed to Angle of Departure (AoD) based on reciprocity to represent a downlink transmission.

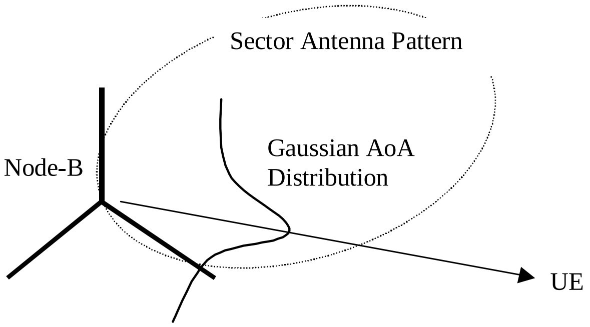
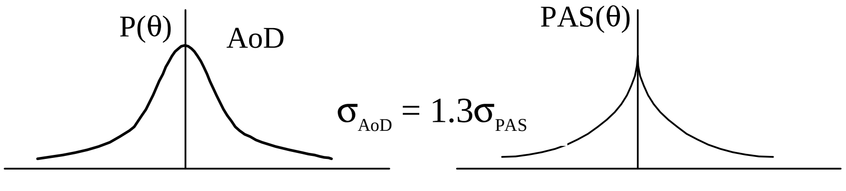


Figure 1. Gaussian distribution for angle of departure from Node-B



Gaussian Probability of Occurrence

Laplacian Power Weighted Spread

Figure 2. Relationship between AoD and PAS

In order to maintain the proper relationship between σ_{AoD} and σ_{PAS}, the power of the rays must generally drop with increasing angle from the reference angle, i.e. reference angle is in the direction of the UE. This makes intuitive sense when including some amount of randomization, which is observed in measurements. This randomness is required to preserve the ratio of about 1.3x which is shown in the reference. The $\sigma_{AoD}/\sigma_{PAS}$ relationship describes the amount of randomness in the measured data, and thus the nature of the spatial distribution of power versus angle. In order to obtain these relationships, a method of randomizing the powers is needed, and a proposed sorting method is given in Appendix A.

Sorting	Result	$\sigma_{AoD}/\sigma_{PAS}$ ratio	Resulting PAS
0%	Completely Random	1.0	Gaussian
60%	Partially Random	1.3	Laplacian
100%	Completely Sorted	1.6	Laplacian

Table 1, Results of sorting based on algorithm in Appendix A

For example as illustrated in Table 1, with completely random assignments of ray powers assigned to the AoDs, the $\sigma_{AoD}/\sigma_{PAS}$ ratio = 1.0. When 100% sorting is used such that rays with decreasing powers are assigned to angles of increasing absolute deviation from the reference direction, the $\sigma_{AoD}/\sigma_{PAS}$ ratio = 1.6. Thus to get a ratio of 1.3 requires partial sorting.

3. RAY DELAYS

Also in [1] is a description of the relationship between the distribution of ray delays and delay spread. The distribution of the occurrence of ray delays is given by an exponential distribution. Corresponding to the increasing delay is a reduction in power also having an exponential decay. Measurements [3] support this basic model for decreasing power with delay with some amount of randomness from sample to sample. The amount of randomness is described by the relationship given in [1] where σ_{delays} is proportional to σ_{DS} such that the ratio of $\sigma_{delays} / \sigma_{DS}$ is approximately 1.3.

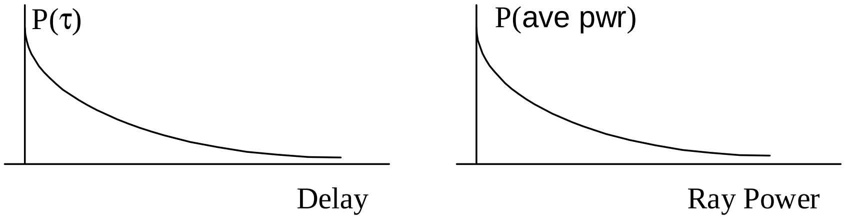
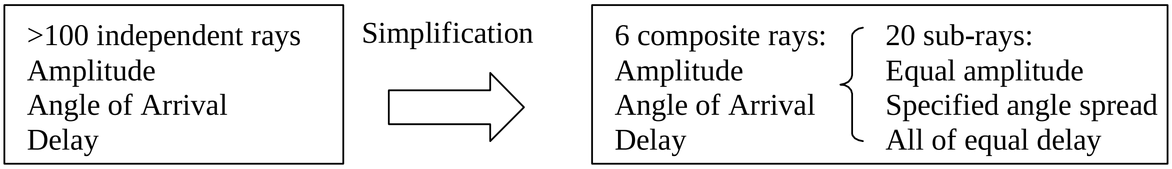


Figure 3. Exponential Ray Delay τ, and Ave Ray Power Distributions

4. CHANNEL MODEL DESCRIPTION

A key parameter in generating a spatial channel model is the number of rays along with their spatial, amplitude, and temporal properties. In order to fully enable the observed behaviors of the channel in a scattering environment, and properly account for the fading and correlation between antenna elements, a very large number of rays is required in a channel model (e.g. > 100.)

With this many independent rays, it quickly becomes difficult and time consuming to manage the generation of rays. A slight modification to this approach is to specify a reduced set of “composite” rays, each being composed of sub-rays. The predefined sub-rays are specified to produce the desired angular spread and temporal fading, thus producing a well defined and predictable behavior for each ray.



The method illustrated, and described below, utilizes a reduced set of “composite” rays, where each ray is now composed of multiple sub-rays. Channel behaviors are characterized by the 120 sub-rays, which inherit the properties of the 6 composite rays. (The 6 rays are now replaced by the 120 sub-rays and are therefore not used in the final calculations of the channel.)

5. CHANNEL GENERATION PROCEDURE

The following procedure proposes a ray-based model for simulating the spatio-temporal channels.

1) Select N rays and their relative powers

A model with a reduced set of N = 6 rays is proposed and illustrated in this procedure. The average powers of the rays are selected from an exponential distribution [3]. The rays are sorted in amplitude based on a randomized sorting procedure given in Appendix A. The rays are then normalized to unity power.

2) Generate a random AS value

Typical cell sites in urban areas have AS distributions with median values of 10-15 degrees. Data presented in [2] showed AS values for Stockholm to be nearly uniformly distributed over a range of 3-28 degrees, and this is our current working assumption. A value of AS is chosen from this distribution. Other distributions are a possible discussion item.

3) Obtain Standard Deviation of AoDs

The standard deviation of the AoDs is approximately 1.3 times the AS[1]. To maintain this relationship, we propose that the standard deviation for the Gaussian angle of departure (AoD) distribution at the Node-B, (used in the next step) be the value of the AS generated in step 2 multiplied by 1.3.

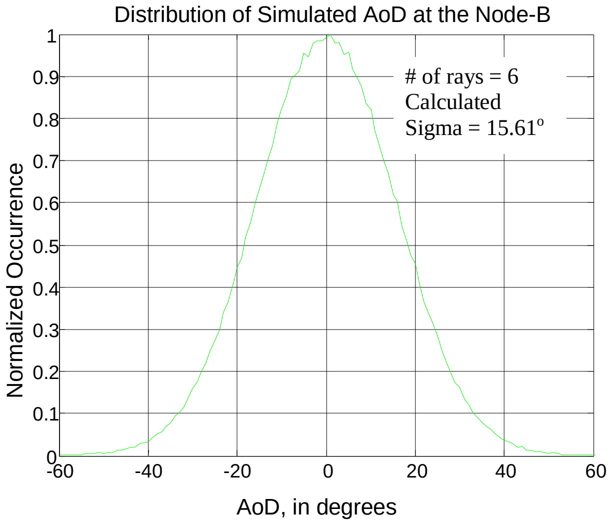


Figure 4, Example of AoD distribution for $\sigma_{PAS} = 12^o$, $\sigma_{AoD} = 12*1.3 = 15.6^o$.

Figure 4 gives an example of a simulated channel where the AS was fixed to a value of 12°. As shown, the statistics are Gaussian with the sigma increased by a factor of 1.3.

4) Generate N AoDs at the Node-B

The mean of the Gaussian distribution of AoDs is in the direction of the UE and the standard deviation is equal to the value generated in step 3.

5) The AoDs are sorted in order of increasing absolute deviation from UE angle

Since there is a trend for stronger rays to occur closer in angle to the direction of the UE than weaker rays, the ray AoDs are ordered to follow this trend. The AoDs are first sorted in order of increasing absolute deviation from the direction of the UE. Then the ray powers, having been sorted with some randomization in step 1, are paired with the AoDs such that the trend of diminishing power corresponds to the ordered increase in absolute angle.

Figure 5 illustrates the simulated PAS when a sort probability of 0.6 is used. The resulting sigma of 11.82° is very close to the expected value of 12° indicating that the sort probability was set to the proper value.

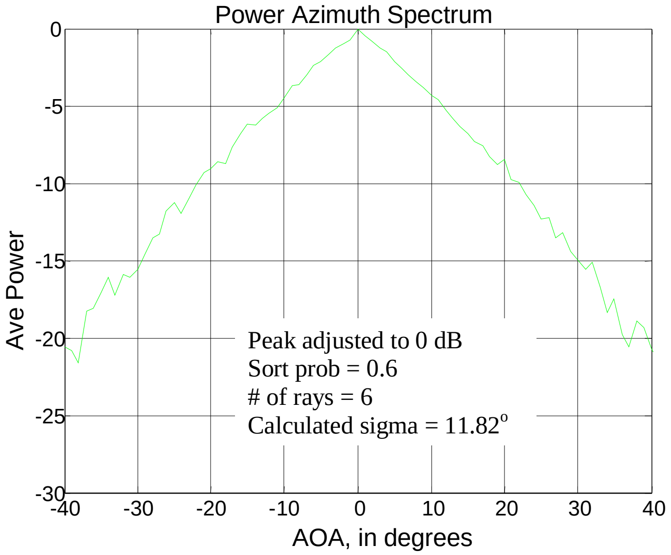


Figure 5, Simulated Azimuth Spread for a fixed Gaussian AoD distribution.

6) Choose an rms delay spread that is correlated to the AS value generated in step 2

The rms delay spread and AS has been shown to be highly correlated (0.72) in [2]. The observed correlation between delay spread and AS should be maintained by coupling these parameters.

From the example in [2] a regression line between Delay Spread and Angle Spread can be written as: DS = 0.12 + 0.058*AS, where DS is the generated RMS delay spread value in microseconds, AS is the azimuth spread in degrees.

To reproduce the variation seen in the data, a noise term can be added to the regression calculation above such that: DS = 0.12 + 0.058*AS + 0.18*N(0,1), where N(0,1) is a Gaussian-distributed random variable with zero mean and unit variance. If the resulting delay spread value is negative, the value is discarded and the process is repeated until a positive value is obtained.

The resulting rms delay spread value will be used in step 7, to scale the generated excess delay values.

7) Generate N excess delays for each of the rays

The excess delay of each ray is chosen from an exponential distribution and then scaled to obtain the rms delay spread obtained in step 6. The N delays are sorted in ascending order. The sorted delays are matched to rays (with a sort probability of 0.3 using the method described in Appendix A) such that the trend of decreasing power is matched to delays of increasing delay. This produces a delay spread profile with an exponential decay, but with some randomness which is typical of measured data.

The delays of the individual rays are then scaled to achieve the desired delay spread value (obtained in step 6) by first dividing each ray value by the current rms delay spread value and then multiplying by the desired rms delay spread value.

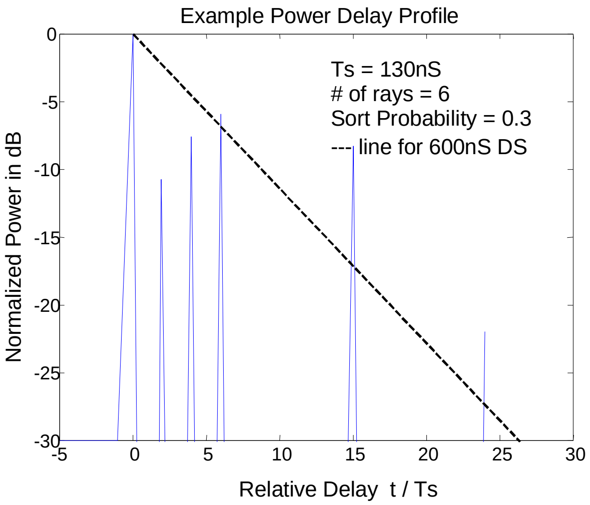


Figure 6, Simulated Power Delay Profile, 6 ray example

Figure 6 illustrates a single channel draw of 6 rays which have been sorted via the procedure in Appendix A, and paired with exponential delays. The delays are scaled to obtain the target delay spread for this trial which was 600 nS. The dashed line indicates an exponential decay with a 600 nS delay spread.

8) Choose 20 sub-rays at the Node-B to replace each of the rays in step 1

The AS of the sub-rays at the Node-B is Laplacian distributed with a standard deviation of one degree [5][6][8] based on matching angle spreads required to reproduce antenna correlations obtained from measured data. To represent the simplest model, the power of each sub-ray is assigned 1/20th the power of each ray in step 1, with uniformly distributed starting phases between [0,2*pi]. The excess delay and average AoD is also inherited from each ray.

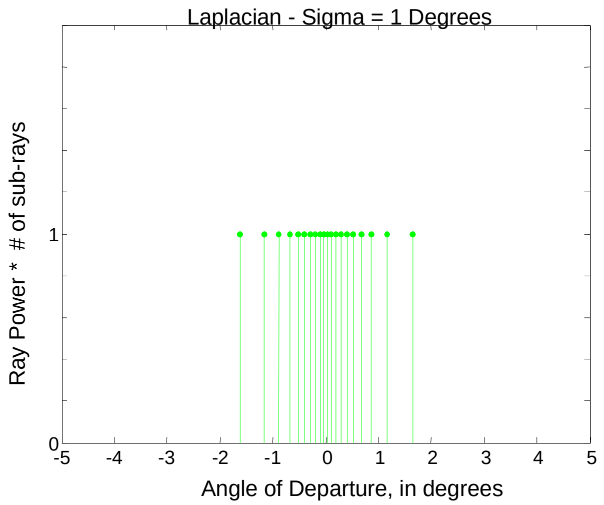


Figure 7, Example distribution of 20 equal power sub-rays to generate a Laplacian spread per ray at the Node-B

9) Choose N AoAs at the UE

Determine the relative power of each ray. Choose the ray AoA from a zero mean Gaussian distribution where the sigma y is given by: y = 104.12*(1-exp(-0.2175*|x|)), with zero in the direction of the Node-B. The fraction of total power in the ray is given by x. Thus strong rays see a more narrow distribution of possible angles, and weak rays see a uniform distribution of arrivals.

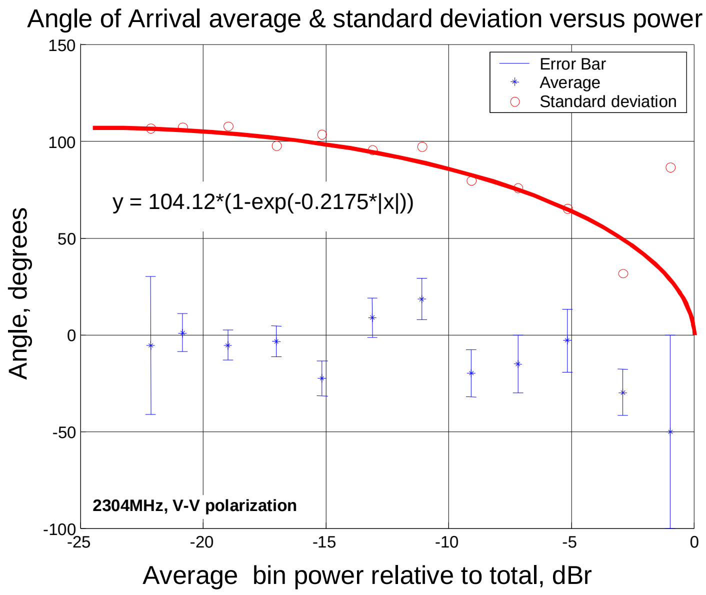


Figure 8, AoA statistics at the UE

The angular distribution of ray arrivals (uniquely resolvable time of arrival) has been assumed by some [4] to be uniformly distributed between 0-360 degrees. However, measurements [2] and [3] indicates that a narrow distribution is needed to model various situations such as street channeling and open areas.

For a light urban area in [3], the median spread of all rays arriving at the UE (without regard to delay) was measured to be on the order of 72 degrees, with the average AoA in the direction of the Node-B. A power dependence was found with weaker rays being more spread, and stronger rays being less spread. The model, shown in Figure 8, gives a spread for the AoA at the UE based on these measurements.

10) Choose 20 subrays for each of AOAs at the UE unit

Each of the N rays are composed of 20 sub-rays in order to define the proper spread. The subrays are of equal constant amplitudes and uniformly distributed starting phases between [0,2*pi]. The angle of the sub-ray at the UE is chosen from a Gaussian distribution with a standard deviation of 35 degrees[6][7] and a mean equal to the ray AoA. This is illustrated in Figure 9. The power of each sub-ray is assigned 1/20th the power of each ray in step 1. The excess delay and average AoA is also inherited from each ray.

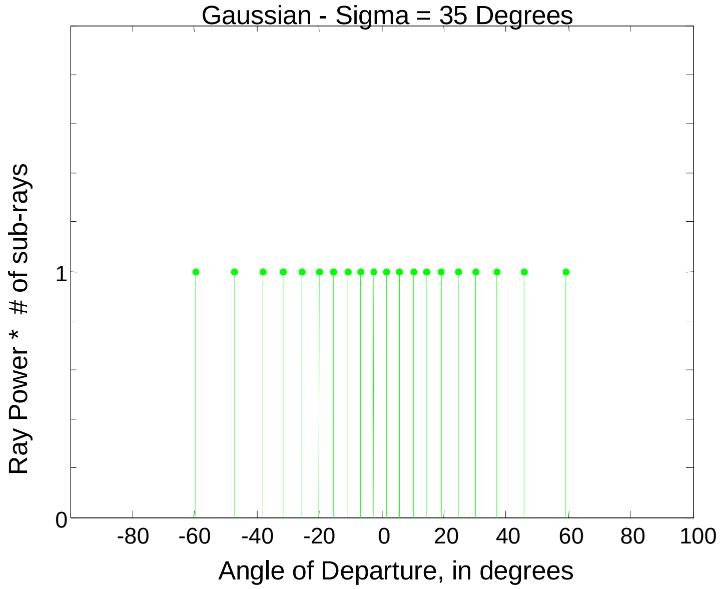


Figure 9, Distribution of 20 equal power sub-rays to generate a Gaussian spread per ray at the UE

6. OTHER PARAMETERS

6.1 Log Normal

Log Normal is currently assumed to be a bulk parameter and independent from the specification of the channel model. This is an issue to be studied further however since path loss has been shown to be correlated to delay spread, which is an integral part of the channel model. Thus future modeling efforts may need to couple the Log Normal or Path Loss to the Delay Spread before the other channel components are selected.

6.2 Antenna Pattern

The effects of antenna patterns are included by applying the appropriate antenna gain to each sub-ray based on its AoA or AoD. The sub-ray components are not renormalized to unity power. This is required in order to present the proper signal as seen by multiple antennas, e.g. antennas in different sectors.

7. CONCLUSION

In this contribution, an approach to a system level spatio-temporal channel modeling has been shown. Channel model parameters and distributions are defined based on various measurements which have been presented in the literature. Careful consideration was made to account for the power-azimuth and power-delay relationships given by the ratios: σ_{AoD} / σ_{PAS}, and σ_{delays} / σ_{DS}. This is necessary to obtain the proper spatio-temporal characteristics.

A multi-step process was illustrated as a technique to generate the spatio-temporal channel.

8. REFERENCES

[1] K. Pedersen, P. Morgensen, B. Fleury, “A Stochastic Model of the Temporal and Azimuthal Dispersion Seen at the Base Station in Outdoor Propagation Environments,” IEEE Transactions on Vehicular Technology, VOL. 49, NO.2, March 2000, pp.437-447.
[2] L. M. Correia, Wireless Flexible Personalized Communications, COST 259: European Co-operation in Mobile Radio Research, Chichester: John Wiley & Sons, 2001.
[3] Motorola, “A Ray Based MIMO Propagation Model”, 3GPP2 TSG-C Submission C50-20010820-027, Portland, OR, August 20-24, 2001
[4] Ulrich Dersch and Roland Ruegg, "Simulation of the Time and Frequency Selective Outdoor Mobile Radio Channel", IEEE Trans. on Veh. Techn., Vol. 42, No. 3, pp. 338-344, August 1993.
[5] Motorola, “Comments on rms AoA spread” 3GPP2 Spatial Channel Modeling Adhoc submission C50-SCM-20020226-002, Feb 26, 2002.
[6] Texas Instruments, “Parameter Values for the Spatial Channel Model“, TSGR1(01)1132, Jeju, Korea, November 19-23, 2001
[7] Motorola, “Mobile Angle Spread Measurements and Angle Distribution Model”, TSGR1#24(02)0408, Orlando, Florida, USA, February 18-22, 2002.
[8] Motorola, “System Level Channel Model and Simulation”, TSGR1#24(02)0407, Orlando, Florida, January 18-22, 2002

This document uses the following terms:
AS – Azimuth Spread of Rays (or sub-rays)– The square-root of the second order central moment of the power weighted arriving or departing rays (or sub-rays) angles, AS = $\sigma_{PAS.}$
AoA – Angle of Arrival – The median of the distribution of arrival angles of a group of sub-rays at the **UE**,
DS – Delay Spread – The square-root of the second order central moment of the power weighted delays,
AoD – Angle of Departure – The median of the distribution of departure angles of a group of sub-rays from the Node-B.

9. APPENDIX A: POWER RANDOMIZATION ALGORITHM

In generating components to simulate a spatial channel, the relationship between power and angle must be considered. Some amount of randomness is needed to distribute power in the spatial and time domains to be comparable to measured data. The following algorithm is proposed as a method to distribute rays with a given distribution of power levels.

1. Rays with given powers are generated, e.g. as in a.) with numerical strength shown

2. A random sequence is generated as shown in b.)
   1 if ran<(x),
   0 if ran>(1-x)

3. If a position is marked for sorting by a “1”, then the occupying ray in a.) is swapped with the ray that would occupy that position when sorted, i.e. based on strength.
Result shown in c.)

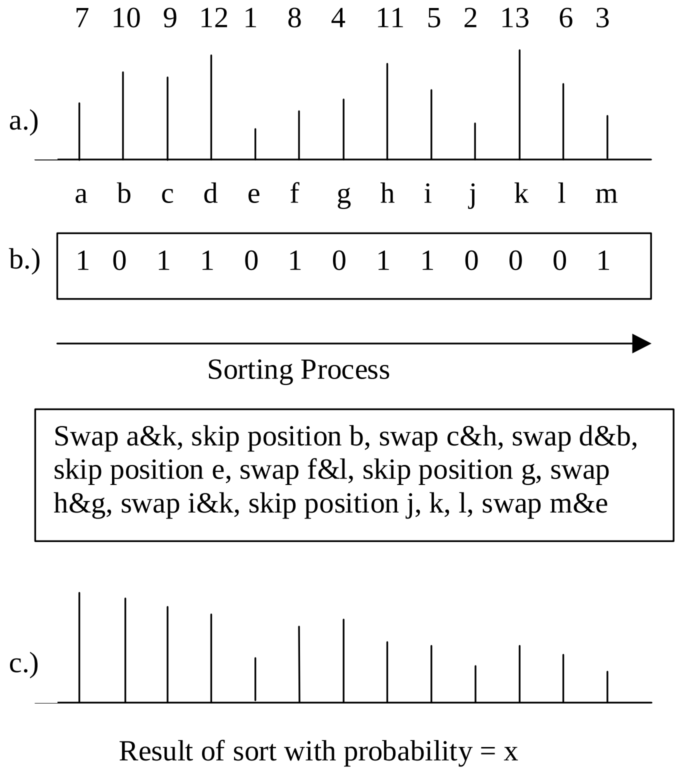

7 10 9 12 1 8 4 11 5 2 13 6 3
a.)
a b c d e f g h i j k l m
b.)
1 0 1 1 0 1 0 1 1 0 0 0 1
Sorting Process
Swap a&k, skip position b, swap c&h, swap d&b, skip position e, swap f&l, skip position g, swap h&g, swap i&k, skip position j, k, l, swap m&e
c.)
Result of sort with probability = x

Figure 10, Example sorting algorithm