

K_0	K_4	K_8	K_{12}	K_{16}	K_{20}
K_1	K_5	K_9	K_{13}	K_{17}	K_{21}
K_2	K_6	K_{10}	K_{14}	K_{18}	K_{22}
K_3	K_7	K_{11}	K_{15}	K_{19}	K_{23}

We discuss now what happens in each of the layers.

4.4.1 Byte Substitution Layer

As shown in Fig. 4.3, the first layer in each round is the *Byte Substitution layer*. The Byte Substitution layer can be viewed as a row of 16 parallel S-Boxes, each with 8 input and output bits. Note that all 16 S-Boxes are identical, unlike DES where eight different S-Boxes are used. In the layer, each state byte A_i is replaced, i.e., substituted, by another byte B_i :

$$S(A_i) = B_i.$$

The S-Box is the only nonlinear element of AES, i.e., it holds that $\text{ByteSub}(A) + \text{ByteSub}(B) \neq \text{ByteSub}(A + B)$ for two states A and B . The S-Box substitution is a bijective mapping, i.e., each of the $2^8 = 256$ possible input elements is one-to-one mapped to one output element. This allows us to uniquely reverse the S-Box, which is needed for decryption. In software implementations the S-Box is usually realized as a 256-by-8 bit lookup table with fixed entries, as given in Table 4.3.

Table 4.3 AES S-Box: Substitution values in hexadecimal notation for input byte (xy)

		y															
		0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
x	0	63	7C	77	7B	F2	6B	6F	C5	30	01	67	2B	FE	D7	AB	76
	1	CA	82	C9	7D	FA	59	47	F0	AD	D4	A2	AF	9C	A4	72	C0
	2	B7	FD	93	26	36	3F	F7	CC	34	A5	E5	F1	71	D8	31	15
	3	04	C7	23	C3	18	96	05	9A	07	12	80	E2	EB	27	B2	75
	4	09	83	2C	1A	1B	6E	5A	A0	52	3B	D6	B3	29	E3	2F	84
	5	53	D1	00	ED	20	FC	B1	5B	6A	CB	BE	39	4A	4C	58	CF
	6	D0	EF	AA	FB	43	4D	33	85	45	F9	02	7F	50	3C	9F	A8
	7	51	A3	40	8F	92	9D	38	F5	BC	B6	DA	21	10	FF	F3	D2
	8	CD	0C	13	EC	5F	97	44	17	C4	A7	7E	3D	64	5D	19	73
	9	60	81	4F	DC	22	2A	90	88	46	EE	B8	14	DE	5E	0B	DB
	A	E0	32	3A	0A	49	06	24	5C	C2	D3	AC	62	91	95	E4	79
	B	E7	C8	37	6D	8D	D5	4E	A9	6C	56	F4	EA	65	7A	AE	08
	C	BA	78	25	2E	1C	A6	B4	C6	E8	DD	74	1F	4B	BD	8B	8A
	D	70	3E	B5	66	48	03	F6	0E	61	35	57	B9	86	C1	1D	9E
	E	E1	F8	98	11	69	D9	8E	94	9B	1E	87	E9	CE	55	28	DF
	F	8C	A1	89	0D	BF	E6	42	68	41	99	2D	0F	B0	54	BB	16

Example 4.8. Let's assume the input byte to the S-Box is $A_i = (C2)_{hex}$, then the substituted value is

$$S((C2)_{hex}) = (25)_{hex}.$$